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NATIONAL TRAINING AND OPERATIONAL TECHNOLOGY CENTER

OPERATIONAL CONTROL PROCEDURES for the ACTIVATED SLUDGE PROCESS

PART I - OBSERVATIONS

PART II - CONTROL TESTS

MAY 1974

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER PROGRAM OPERATIONS

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16. ABSTRACT

This is a series of technical reference materials on the process control of activated sludge. It describes activated sludge process procedures based on sludge quality and solids inventory. It consists of the following parts: Observations and Control Tests, I and II. Describes the interpretation of process status and requirements from physical observations; and control tests used for process control. Calculation Procedures, III-A. Describes the calculations used with the control test results to develop the necessary process status and control decision information. Calculation Procedures for Step-feed Process Responses, III-B. Describes the special calculational procedures required for the step-feed configuration on the activated sludge process. Addendum No. 1. Presents simplified step-feed calculations and corrections to Part III-B. Updated Summary - January 1978. Provides an updated summary of the operational control procedures with new material on sludge quality and process control and expanded versions of return sludge flow control which considers most types of sludges encountered in actual practice. Return Sludge Flow Control. Describes a method for determining the return sludge flow rate for sludges of fair to good quality using information developed from the control tests. Appendix. Describes data presentation techniques useful in process control, testing equipment used in performing control tests, and symbols and terminology.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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OPERATIONAL CONTROL PROCEDURES FOR THE ACTIVATED SLUDGE PROCESS

PART I - OBSERVATIONS

PART II - CONTROL TESTS

by

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MAY 1974
(Revised Mar., 1978)

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF WATER PROGRAM OPERATIONS

FOREWORD

The National Training and Operational Technology Center is developing a series of pamphlets describing Operational Control Procedures for the Activated Sludge Process. This series, describing the "NTOTC Procedures", will include Part I OBSERVATIONS, Part II CONTROL TESTS, Part III CALCULATION PROCEDURES, Part IV SLUDGE QUALITY, Part V PROCESS CONTROL and an APPENDIX. Each of these individual parts will be released for distribution as soon as it is completed, though not necessarily in numerical order. The original five-part series may then be expanded to include case histories and refined process evaluation and control techniques.

This pamphlet has been developed as a reference for Activated Sludge Plant Control lectures I have presented at training sessions, symposia, and workshops. It is based on my personal conclusions reached while directing the operation of dozens of different activated sludge plants. This pamphlet is not necessarily an expression of Environmental Protection Agency policy or requirements.

Parts I and II were originally printed as separate pamphlets dated April 1973. The May 1974 printing combines the two Parts which includes some revision concerning use of the centrifuge and dilution settlometer tests.

The mention of trade names or commercial products in this pamphlet is for illustrative purposes and does not constitute endorsement or recommendation for use by the Environmental Protection Agency.

Alfred W. West

PART I

OBSERVATIONS

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OBJECTIVES

Aeration tanks and final clarifiers are studied perceptively for informative physical characteristics that help identify sludge quality and process status. They are scrutinized for clues that indicate the kind of control adjustments needed to achieve optimum plant performance. The inferences of such physical findings are used to supplement the results of other more specific control tests that dictate the direction and magnitude of the essential control adjustments.

INTRODUCTION

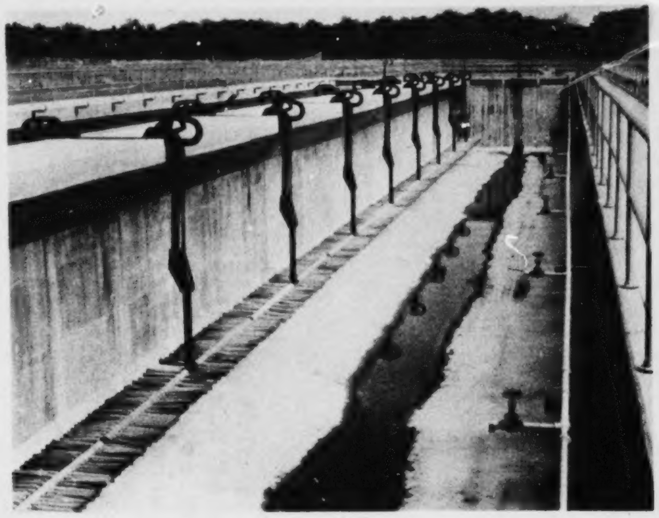
Much can be learned from simple but perceptive sensory observation of process features such as the type, color, and extent of foam on the aeration tank surface and the presence or lack of scums and rising floc particles in the final clarifiers. From such observations, a skilled operator usually can determine the basic phase his process is moving towards or is locked into. Such observations will make him aware of more generalized long-term requirements. They will help him reach proper conclusions from the results of other more specific control tests that are used to calculate process demands and to determine the type and extent of control adjustments that are actually needed.

The entire series of physical observations described in this section should be made each time the routine control tests are performed. The appearance of the final effluent and the aeration and clarifier tank contents should be examined at least once during each operator's eight-hour shift.

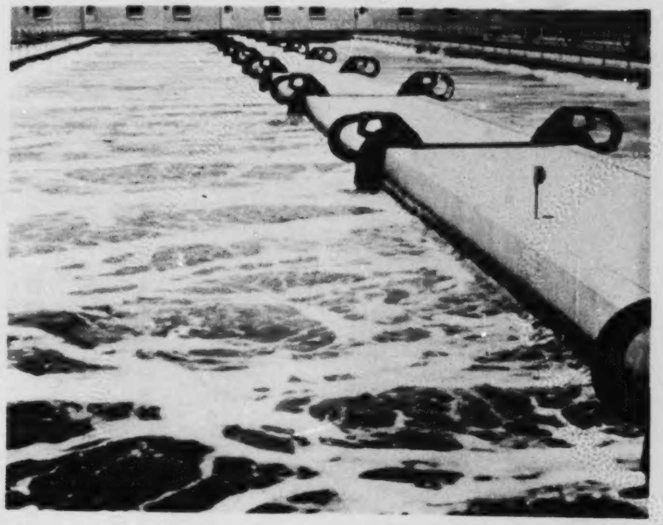
AERATION TANKS

TURBULENCE

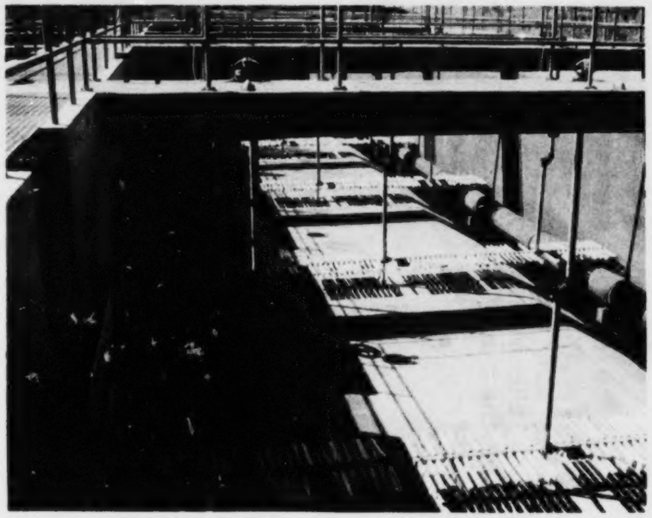
The operator should observe the entire aeration tank surface for turbulence. Though some of his conclusions will be subjective and based on past experience, the extent of surface turbulence will indicate whether or not all sewage, return sludge, and mixed liquor are thoroughly mixed throughout the entire aeration tank. Observable surface



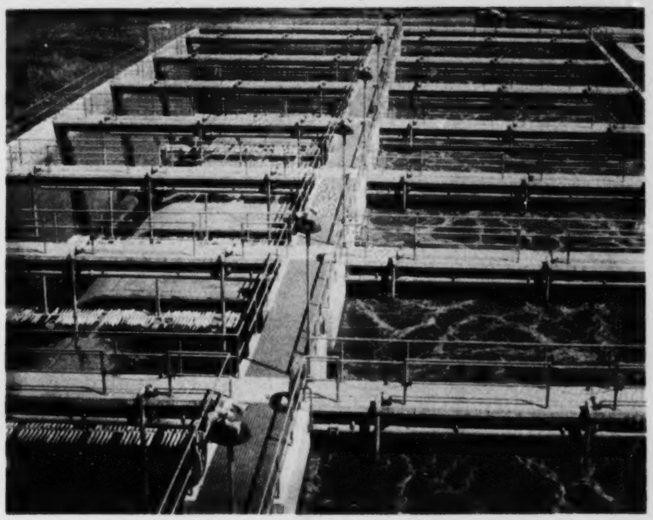
COMPRESSED AIR - SPIRAL FLOW
Showing Diffuser Socks



COMPRESSED AIR - SPIRAL FLOW
In Use



COMPRESSED AIR - CROSS ROLL
Showing Diffuser Socks



COMPRESSED AIR - CROSS ROLL
In Use

characteristics will imply whether or not dead spots or insufficiently mixed core areas may exist within the aeration tanks. The operator should maintain, increase, or decrease air discharge rates according to the conclusions he reaches from the results of such observations and from supplementary dissolved oxygen determinations.

He should reproportion air flow through headers or individual subheaders to correct any dead spots, unequal air distribution, or inadequately tapered aeration intensity that may have been observed.

If serious mixing deficiencies prevail despite corrective air distribution adjustments, he should attempt to determine which structural, mechanical or design deficiencies may be responsible for the difficulties. If normal air balancing procedures fail to correct evident defects, he should be prepared to recommend the maintenance or modification procedure that may be necessary to eliminate the problems.

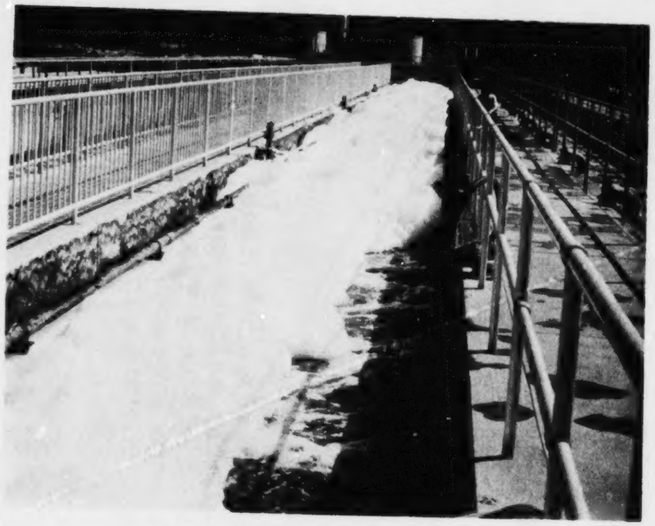
In many cases, aeration deficiencies can be corrected by routine diffuser cleaning or by replacing existing diffusers with more effective maintenance free units. In some cases, major mechanical alterations may be required to relocate and increase the number of diffusers to mix and aerate the tank contents thoroughly. Overall process performance has been improved at some plants by replacing the single run of diffusers that extended along one side wall with multiple parallel runs of diffusers extending either longitudinally or across the tank bottom.

SURFACE FOAM AND SCUM

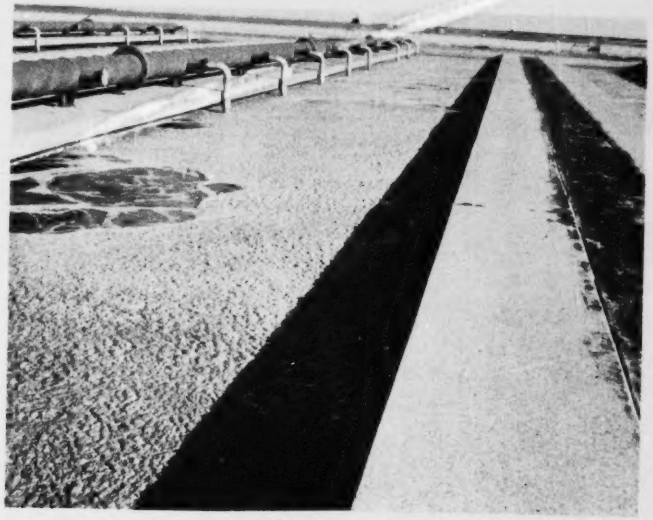
The type of foam or scum, if any, accumulated over the aeration tank surface, and to a lesser extent, the color of the mixed liquor sludge reveal process status and indicate generalized long-term sludge wasting requirements.

Fresh Crisp White Foam

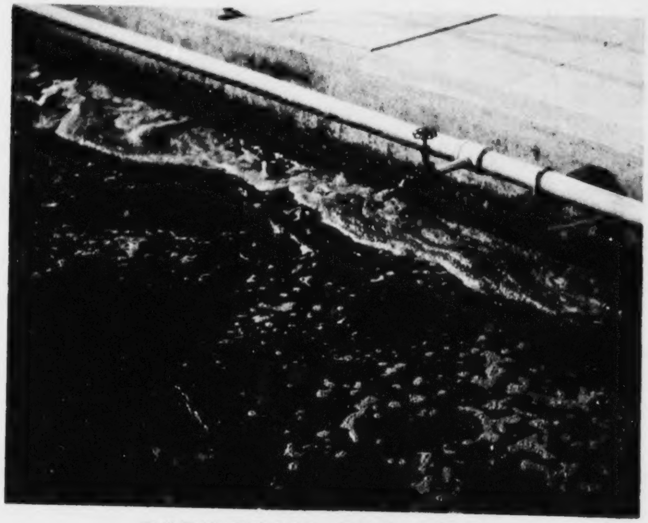
Only a modest accumulation of white, or at least light colored, crisp appearing foam is usually evident on aeration tank surfaces when an excellent final effluent is produced by a properly balanced activated sludge process. Under such circumstances the operator should continue his successful



BILLOWY WHITE FOAM
(Young Sludge)



THICK DARK TANK FOAM
(Old Sludge)



DARK FOAM, BAD ODOR
(Septic Sludge)

control policies until the physical characteristics or the results of other control tests diverge from optimum.

Excessive Billowing White Foam

If the aeration tanks are covered by thick voluminous billows of white sudsy foam, the operator can be quite certain that the sludge is too young and that sludge age should be increased by reducing the sludge wasting rate.

Sludge age, which is controlled by the sludge wasting rate, indicates the approximate number of days that the activated sludge remains in the system before being discarded. Prolonged excessive sludge wasting will reduce sludge age by increasing the proportionate amount of newly developed floc in the system. Conversely, unduly low wasting rates will increase the number of days the sludge is retained in the system and will increase the proportionate amount of older sludge.

Sludge wasting rates should be decreased only gradually on a day-to-day basis to correct the process imbalance that was revealed by the excessive white foam. Best results are usually obtained by reducing the wasting rate approximately twenty percent on each successive day until all observations and tests reveal an improving trend. When positive improvement is noted, the operator should maintain the lowered wasting rate for about three more days while the improving trends are confirmed. He should, of course, continue to plot and review process control and response trends which will alert him to subsequent control adjustment policy that may become necessary. As implied previously, wasting usually should not be discontinued completely. Exceptionally low sludge settling rates and classic bulking that can accompany this type of foam generation may be corrected by reducing air discharge rates to lower the mixed liquor dissolved oxygen concentration to the 0.5 to 1.0 mg/l range.

Thick, Scummy, Dark Tan Foam

At the other extreme, the operator may observe a more dense and somewhat greasy scummy layer of deep tan to brown foam covering the entire aeration tank surface. Such a foam almost always indicates that the sludge is too old and possibly over oxidized. The obvious answer is to increase sludge wasting rates. Here again, the sludge wasting rate should usually be increased modestly, possibly twenty percent per day, on a day-to-day basis while observing trend lines to determine the maximum wasting rate that should be maintained until the difficulties are overcome and the process is restored to proper balance.

SLUDGE COLOR AND ODOR

At times a poor quality extremely dark brown-colored sludge, sometimes almost black, releasing hydrogen sulfide odors, may be observed in the aeration tanks. It does not take much experience to recognize this problem. Most operators would logically increase air discharge rates immediately to provide 2 - 3 mg/l DO throughout the tank contents. In severe cases, when such color and odor persists, despite proper control measures, they should question the adequacy of the aeration devices installed at their plants. Under such circumstances, the operator should clean or replace the existing diffusers and recommend appropriate mechanical modifications as discussed in the section on turbulence and mixing.

The operator should also observe the final effluent and the clarifier water surface critically for additional clues to indicate process phase and balance, and to supplement the results of other control tests to determine sludge wasting and air control requirements.

FINAL EFFLUENT APPEARANCE

If the final effluent appears clear and attractive, or is improving day by day, obviously the operator should continue his present control policy if all control measurements are in the proper range.

Conversely, if it appears turbid or contains noticeable solids, he should modify his operational control policies and procedures. Though observation of poor effluent quality alone will not reveal specific control requirements, it signals the need for judicious review of control and response trends and for revised operating policies. Specific control adjustments will be dictated by the results of other control tests.

FINAL CLARIFIER SURFACE APPEARANCE

Sludge Bulking

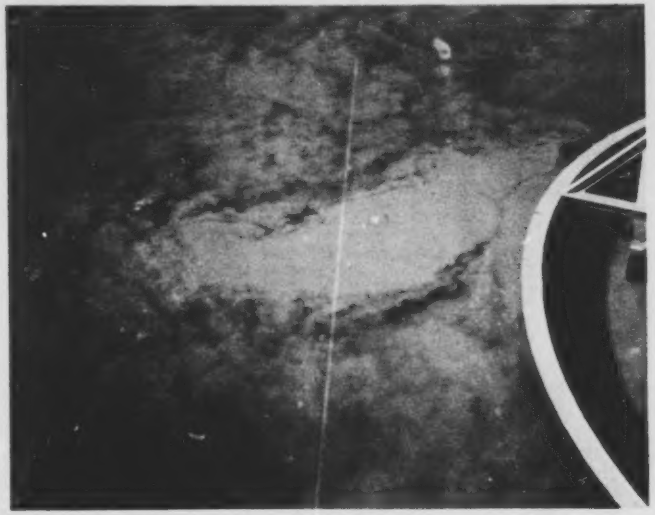
Operators who have experienced true classic sludge bulking find it all too easy to remember and identify. Such conditions are evidenced by a homogeneous appearing sludge blanket that extends throughout the entire clarifier, and can be observed at the water surface while the mixed liquor solids pour out over the final effluent weirs. Though at times induced by shock loadings, and aided and abetted by ineffective aeration devices, classic sludge bulking usually is caused by improper operational control rather than by inadequate plant capacity. Furthermore, impending bulking usually can be recognized from the trend charts (Appendix) and by judicious use of the sludge depth blanket finder (Part II Control Tests) many days before it actually occurs.

This type of bulking, which is practically always associated with young sludge, usually can be eliminated by reducing sludge wasting rates, increasing return sludge flow rates, and reducing air discharge down to the minimum rates that will maintain aerobic conditions in the aeration tanks. Where appropriate flexibility has been designed into plants, bulking has also been eliminated by changing the process mode from conventional plug flow to step flow by introducing the primary effluent into the second or third bay of the aeration tank.

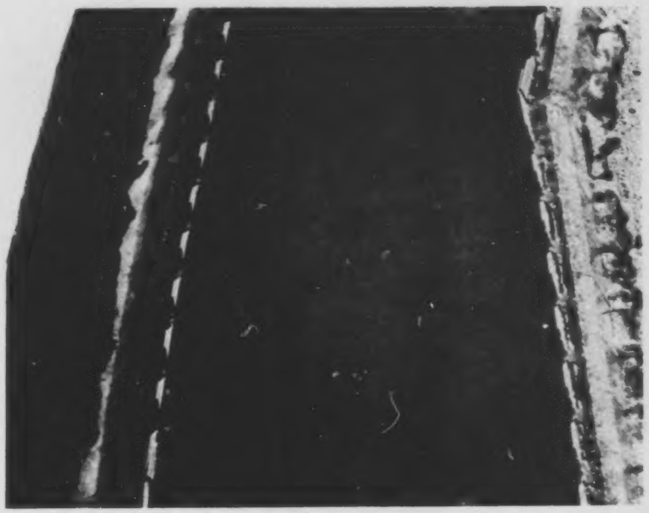
In some cases where such control adjustments have failed, emergency chemical treatment has cured classic sludge bulking. Some operators have successfully applied polymers and ferric chloride or alum to the mixed liquor entering the final clarifier without destroying desirable sludge characteristics. Laboratory jar tests should be performed to indicate the type of chemical, the dosage rate, and the pH range that will be most effective. If the chemical additives do not cure actual bulking in the final clarifiers, even though the sludge samples settled and compacted in the laboratory jar tests, the chemicals should be added at different points between the aeration tanks and the final clarifiers until best results are obtained. It is usually best to apply chemicals to the wet well preceding, or the pipe line leading to, the final clarifier.

Sludge Solids Washout

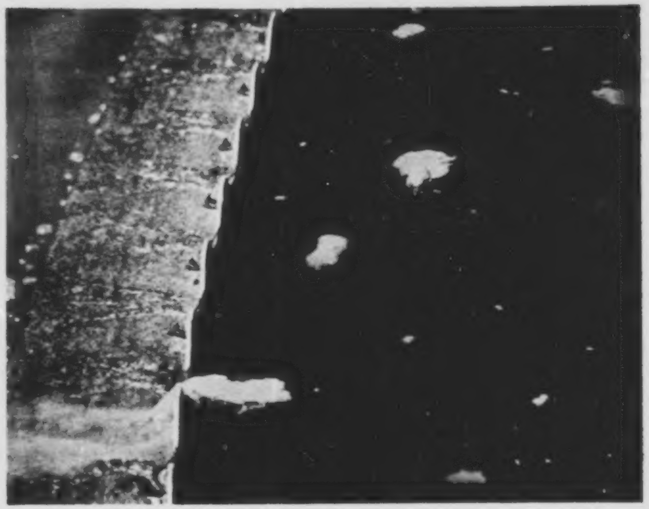
Excessive sludge washout over the final effluent weirs, when the upper surface of the sludge blanket is more than



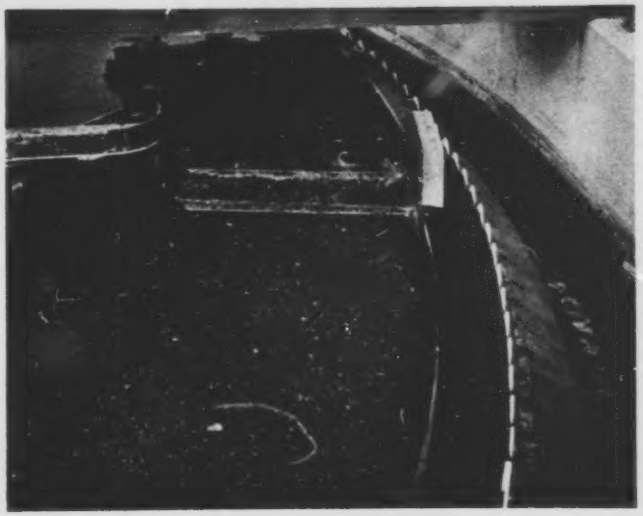
CLASSIC SLUDGE BULKING



SOLIDS WASH OUT



RISING CLUMPS



FLOATING ASH

three feet below the clarifier water surface and when sludge settles properly in the laboratory, should not be confused with classic sludge bulking. At times this type of severe effluent degradation has been observed while the settlometer test revealed excellent sludge quality. In many multiple clarifier plants this has been caused by unequal mixed liquor flow into, or by unequal return sludge removal from, individual final clarifiers. Under such circumstances, where excessive velocity currents are induced, every effort should be made to balance flows into and out of the clarifiers.

Solids washout has also been caused by hydraulic overloading, by improper clarifier inlet port arrangements, and by faulty final effluent weir locations. Differing from classic sludge bulking, this type of problem is more frequently caused by hydraulic overloads or inappropriate final clarifier design rather than by operational control procedures.

Clumping and Ashing

At times, large masses of sludge, possibly as large as one foot in diameter, may be seen rising, then bursting, and finally spreading over the clarifier surface. This has sometimes been called "clumping". At other times, smaller sludge particles, usually deep brown to gray in color, may rise and then spread over the tank surface. Some operators call this "ashing". This problem usually occurs when sludge age has been permitted to increase beyond the optimum equilibrium requirement of the process cycle and it can usually be eliminated by increasing sludge wasting rates. Reducing air discharge rates to the minimum levels that will still maintain aerobic conditions in the aeration tanks has also been helpful.

Straggler Floc

At times, small, almost transparent, very light fluffy, buoyant sludge particles (one-eighth to one-quarter inch in diameter) may be observed rising to the clarifier surface near the outlet weirs. This condition is usually intensified in a shallow clarifier and may be especially noticeable at high return sludge flow rates. When this type of straggler floc is observed while the final effluent is otherwise exceptionally clear, and particularly if it prevailed even during relatively low surface overflow rates, it implies that sludge age should be increased moderately towards optimum. Since this type of straggler floc usually occurs at relatively low mixed liquor solids concentrations and is usually intensified during the early morning hours, it is believed that these particles are fresh, low density portions of new sludge that have been built up over night. Straggler floc formation can be minimized, by reducing sludge wasting rates moderately to increase sludge age while return sludge and air discharge rates are controlled to meet process demands that are calculated from other control tests.

Pin Floc

At other times, very small compact pin floc, usually less than one-thirty-second of an inch in diameter, may be observed suspended throughout moderately turbid final clarifier tank contents. This is a strong indication that sludge age has been increased unduly, and the sludge has become overoxidized. This will be confirmed by the settlometer test if rapidly settling discrete sludge particles appear granular rather than flocculant, and accumulate rather than compact while forming a settlometer sludge blanket. In essence, granular sludge particles were falling through a turbid liquor rather than compacting and squeezing out a clear final effluent.

When these final clarifier characteristics are confirmed by the settlometer test, the sludge wasting rate should be increased while return sludge flow is adjusted to meet other control test demands.

PART II

CONTROL TESTS

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OBJECTIVES

Control tests, that can be run as frequently as needed throughout each 24-hour cycle, reveal sludge quality, process status, and final effluent quality.

Results of the settlometer, centrifuge and final clarifier sludge blanket level tests are used to calculate solids distribution ratios between the aeration tanks and the final clarifiers, sludge detention time in the final clarifiers and other factors influencing process performance.

The coordinated results of the full test series, including flow records, turbidity, and dissolved oxygen test data, are ultimately used to determine the return sludge flow, excess sludge wasting and air discharge rates needed to maintain or restore excellent final effluent quality.

INTRODUCTION

Practically all information needed to define sludge quality and process status and to calculate control adjustment requirements can be determined from the results of a few relatively simple tests. The entire series of settlometer, centrifuge, sludge blanket depth, effluent turbidity and dissolved oxygen tests can be completed in about ninety minutes and can, therefore, be run as frequently as needed throughout each 24-hour cycle. The complete test series should be run at least once every eight-hour operating shift. The sludge blanket and the fifteen minute centrifuge tests should be run more frequently whenever rapidly changing process characteristics demand more critical scrutiny and control. Though simple, informative, and too frequently neglected, these tests are neither new nor difficult. They were, in fact, proposed by E. B. Mallory more than thirty years ago. Though the testing techniques and some of the data processing methodology includes that proposed by Mallory, the procedures and calculations for determining control adjustment requirements, as discussed in these pamphlets, were developed by me.

These discussions include only those control tests that are used directly to identify process performance and to dictate process control adjustments. Other important monitoring type tests, such as BOD, COD, etc., are not included in these discussions.

METER READINGS

Each control test series should be started by reading plant meters to record flow data that are needed to determine process requirements.

Flow records specifically related to control of the activated sludge process include:

AERATION TANKS

Total influent waste water flow to aeration tanks
Return sludge flow to aeration tanks
Total air to aeration tanks

FINAL CLARIFIERS

Mixed liquor flow to clarifiers
Sludge removed from clarifiers

EXCESS SLUDGE TO WASTE

Mixed liquor wasted
Return sludge wasted

The extent of additional flow data needed to evaluate and control total plant performance will vary from plant to plant. Other waste streams that should also be measured could include:

Raw sewage flow
Plant drainage recycled to primaries
Primary sludge flow
Sludge thickener flows
Sludge filtrate flows
Digester supernatant flow
Sludge removed from plant
Plant drainage recycled to aeration tanks
Final effluent reuse
Final effluent flow

The following discussion is limited specifically to the activated sludge portion of the treatment plant. For multiple tank plants, having three aeration tanks and three final clarifiers, for example, the operator should also routinely maintain equal hydraulic loading to each of the parallel operating units.

The following flow rates should be determined during each test period and the 24-hour totalized value of each should be recorded every day.

SEWAGE FLOW INTO EACH AERATION TANK

Frequently overall treatment is impeded when aeration tank loadings cannot be, or are not, balanced properly between the parallel aeration tanks. The better treatment provided by an underloaded tank unit will not compensate fully for the poorer treatment provided by the overloaded unit.

RETURN SLUDGE FLOW INTO EACH AERATION TANK

Maldistribution of return sludge flow, especially when coupled with unequal sewage flow loading between parallel aeration tanks, can further distort the proportionate purification pressures (mixed liquor concentration and detention times) and reduce treatment capability.

AIR DISCHARGE TO EACH AERATION TANK

Here, again, unequal distribution as well as inadequate or excessive total air flow can degrade sludge quality and purification. The basic indicating, recording, and totalizing meters should be used to measure and control air flow to each aeration tank. Simple indicating meters should be observed to assure proper air distribution to the main air headers feeding each bay or compartment of individual aeration tanks.

MIXED LIQUOR FLOW INTO EACH FINAL CLARIFIER

The influent flow to each clarifier should be determined during each test period so that the surface overflow rates and the solids loadings can be distributed properly to each clarifier. This is especially important during troublesome times when rising sludge blankets warn that classic sludge bulking may be imminent.

If the clarifier flows are not balanced properly at such times, mixed liquor sludge can be forced out over the final weirs of the overloaded clarifier, while the sludge blankets in the other clarifiers may remain low enough to produce a clear effluent. Unfortunately, this may occur when proper flow distribution could otherwise have held the sludge blankets safely below the water surface of all clarifiers.

SLUDGE REMOVED FROM EACH CLARIFIER

These meters, one for each tank, should also be read at each test period and the totalized value should be recorded each day. Here again, the need to balance sludge removal from all clarifiers to maintain proper sludge blanket level control is obvious.

EXCESS SLUDGE FLOW TO WASTE

This meter, or meters, should be read at every test period and whenever the wasting rate is changed.

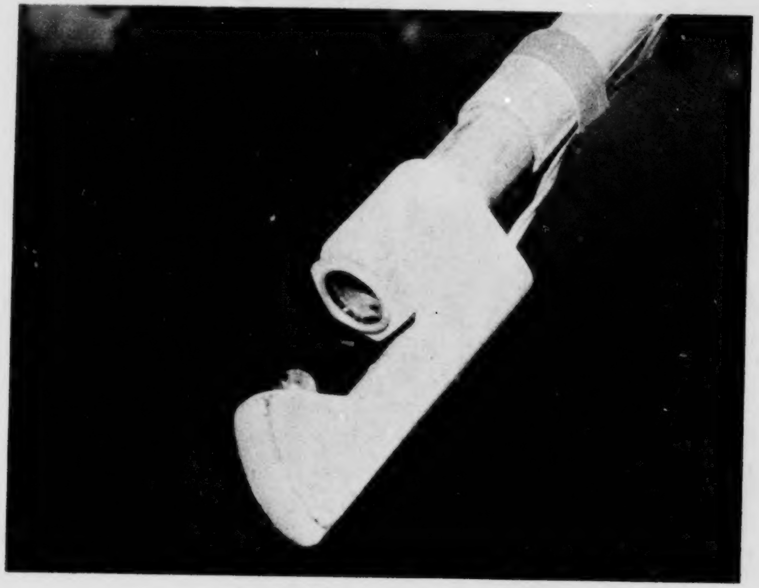
Procedures to use flow data and other control test results to determine return sludge, waste sludge, and other process requirements will be discussed in other parts of this pamphlet series.

DEPTH OF SLUDGE BLANKET

After checking the meters, an operator following a logical test schedule should move on to determine final clarifier characteristics. He should determine the depth of the sludge blanket that has accumulated within the clarifier and observe conditions at and near the water surface.

Various types of sludge blanket depth finders are used. The type described in the Appendix can be constructed simply and used conveniently; and when handled properly, it becomes a valuable, reliable operational control tool. At least two sludge blanket finders should be provided to assure continuity of test results, especially when one is being repaired. One should be long enough to reach from the bridge to the tank bottom. The other shorter one should only be long enough to extend about half way down into the tank.

Two other types of blanket finders are wands with photo-electric cell actuated buzzers and a series of small



SLUDGE BLANKET FINDER
LIGHT AND SIGHT GLASS

OPERATOR STARTING
DEPTH OF BLANKET TEST

airlift pumps extending down to different measured depths within the final clarifier. The operator should use the type he finds most convenient, but it is suggested that the reliable pipe and sight glass type be provided, at least as a back-up instrument.

It takes a little practice for an operator to use a blanket finder, or, more exactly, to know what he is looking for, but after the first few diligent attempts he will be surprised at how accurately and easily blanket depths can be determined.

A cross section of most clarifiers containing a reasonably good sludge solids distribution balance may reveal a zone of discrete straggler floc particles settling down to form the blanket. Somewhat farther than half-way down into the tank, there will usually be a distinct plane of demarcation between the individual settling sludge particles and the relatively thin, but quite homogeneous, upper surface of the accumulated sludge blanket. Then the concentration of this sludge blanket will usually increase in density down to the zone of maximum compaction at the very bottom of the tank.

Here are two precautions - which will only be resolved by practice. Do not stop the downward movement of the blanket finder when the individual discrete sludge particles are observed. Secondly, do not force the blanket finder down to the point where the denser sludge within the blanket actually obscures the light. Instead, move the blanket finder down at a rather rapid uniform rate through the clear liquor, then continue down through the zone containing individual floc particles, and finally stop when the upper surface of the definite homogeneous sludge mass is observed. Take your reading at this point; you have reached the upper surface of the sludge blanket.

The blanket reading station should be located at a point where the single measurement will approximate the average depth of the entire sludge blanket. A station on the final clarifier bridge, about one-third of the tank radius in from the outer tank wall, will usually satisfy this requirement. The selected station should be marked so that blanket depths are always measured at the same location.

SAMPLE COLLECTION

Samples for the control tests and other laboratory work must be collected on time, from appropriate locations, and according to approved procedures; and they certainly must be representative. These elementary principles can not be violated without cost.

CENTRIFUGE TEST SAMPLES

After observing the clarifiers, return sludge samples should be collected for the centrifuge test. Selection of the sampling station for collecting samples that truly represent the actual quality of the entire return and waste sludge flow is most important. It is best to collect the sample from the point where the thoroughly mixed return sludge from all clarifiers enters the aeration tanks. If such location is inaccessible, the sample should be taken from a tap off the return sludge pump discharge header. The sample pipe should obviously be flushed out thoroughly before each sample is collected. Since mixing may be inadequate, sampling from deep wet wells should be avoided if at all possible.

In addition to the sample collected for basic plant control, individual return sludge samples should be collected from each final clarifier to check or to balance multi-tank performance.

At times, samples should be collected from each of the individual sludge draw-off tubes in each final clarifier. This series of samples need be collected only as frequently as required to assure uniform sludge withdrawal from the entire clarifier floor area. Ordinarily, such "trim spin" samples are collected about once each week.

The samples collected for the settlometer test, as described in a following section, will also be used to determine the centrifuged concentration of the mixed liquor solids.

TURBIDITY TEST SAMPLES

Special samples should also be collected from the final clarifier to determine the turbidity of the treated waste. These samples for turbidity should be collected deliberately from the clearest area of the final clarifier water surface that contains the least surface sludge or scum that may be present. When collected in this manner, these samples will indicate specific process performance, undistorted by clarifier or other equipment defects that may need correction. Other 24-hour composite samples collected for plant monitoring (BOD, COD, TSS, etc.) will be used to determine net process performance.

SETTLOMETER TEST SAMPLES

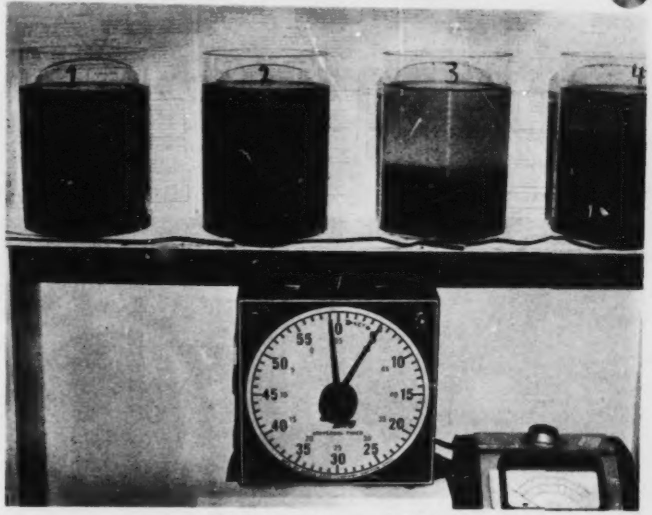
The mixed liquor sample for the settlometer test should be collected last of all. This sample, which should represent the average quality of all mixed liquor flowing out of all aeration tanks, will also be used to determine solids concentration both by centrifuge and by weight. Preferably, this sample should be collected from the common discharge flume that contains all mixed liquor flowing from the outlet of all active aeration tanks. If the common discharge header is inaccessible, equal volumes of mixed liquor should be collected from the outlet end of each aeration tank and composited into a single representative sample for the settleability and solids concentration tests.

The necessity for collecting mixed liquor samples in wide-mouthed containers, rushing the samples to the laboratory, and starting the settlometer test immediately, can not be over emphasized. After collection, the samples should be subjected to the absolute minimum amount of agitation and aeration. Improper sample handling, such as violent shaking or splashing, or unwarranted delay between the time that the sample is collected and the time it is poured into the settlometer, can alter sludge settling characteristics and induce erroneous settlometer test results.

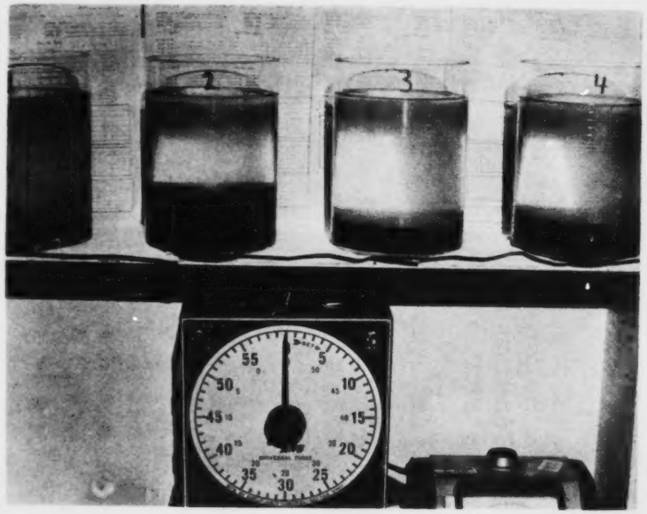
SETTLOMETER TESTS

Preferably, mixed liquor sludge settleability tests should be determined in a clear glass cylinder with a larger diameter and a lesser depth than the standard 1,000 cc graduated cylinder that is frequently used for this test. A glass cylinder shaped similar to the standard two-liter beaker, but with better graduations and without the rounded bottom edge, would be satisfactory. Many operators now prefer the five inch diameter, six inch graduated depth, two-liter Mallory settlometer that is graduated in tenths and hundredths of the settlometer volume. Satisfactory settlometers can also be fabricated from five inch diameter clear plexiglass cylinders.

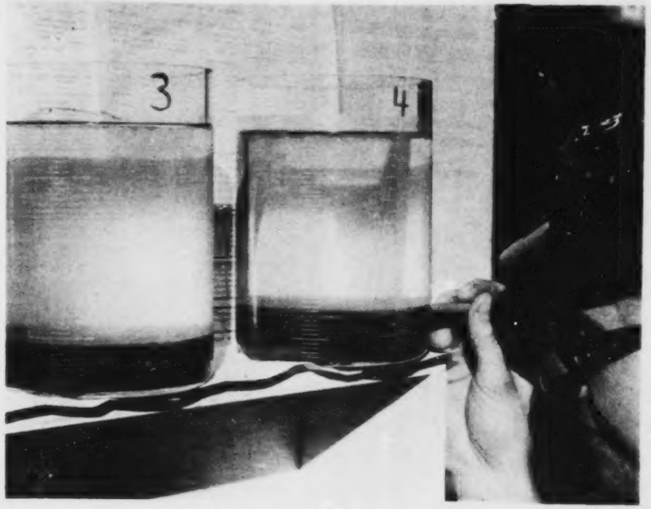
TEST SET-UP



5 MINUTE READING



1 HOUR APPEARANCE



1 HOUR READING

SETTLOMETER TEST

The mixed liquor sludge sample should be stirred and then poured into the settlometer carefully and rapidly and with the least possible amount of additional aeration or disturbance. The settlometer contents should then be stirred gently to assure thorough mixing; then all swirling should be dampened immediately with a wide paddle (four inch sheet aluminum works well) before the timer is started.

The volume of the settlometer occupied by settled sludge should be read and recorded at every five-minute interval for the first thirty minutes and then every ten-minute interval for the second thirty minutes of the one hour settlometer test. This is the standard test duration.

When sludge settles extremely slow, or when bulking actually occurs, the settlometer test period should be extended beyond the one hour reading. By returning to observe the settled sludge volume after 2, 3, 4, etc. hours, the operator will be able to determine ultimate sludge compaction for a more thorough process evaluation.

Running simultaneous multiple settlometer tests on diluted specimens of slowly settling mixed liquor can help the operator decide whether to increase or decrease the sludge wasting rate. At least two dilutions should be made. One settlometer should contain undiluted mixed liquor, one should contain about 75% mixed liquor diluted with 25% final effluent, and a third settlometer should contain half mixed liquor and half final effluent.

Though this expanded multiple dilution test need be run only once per day while the slow settling problem persists, it should follow the previously stated standard procedures. If confirmed by other control test results, these multiple settlometer test results can reveal the following control adjustment needs.

If the diluted samples settle much more rapidly than the undiluted sample (especially during the first 10 minutes), the system contains too many fair to good quality mixed liquor solids and sludge wasting should most probably be increased.

If the diluted samples settle at the same rate, or only slightly faster than the undiluted mixed liquor sample (especially during the first 10 minutes), the mixed liquor sludge is truly bulky. This has been caused frequently by excessively heavy wasting which reduced sludge age way below the optimum. Sludge wasting should usually be reduced (but not down to zero) modestly, day by day, to develop a sludge that can concentrate more.

Operators who set up a test cylinder, walk away, and then return for only one single observation after thirty minutes, miss most of the information that actually defines sludge quality. A single thirty-minute test, to determine SVI, is somewhat like a five-day BOD, in that it reveals only one point in a progressive reaction and it will not help an evaluator who is really interested in reaction rates and the full impact of ultimate demands.

The first five-minute reading is one of the two most important observations for this test. During this first five minutes the conscientious operator will critically observe how the sludge particles agglomerate while forming the blanket. He will see whether the sludge compacts slowly and uniformly while squeezing clear liquid from the sludge mass or whether tightly knotted sludge particles are simply falling down through a turbid effluent. He will also observe how much and what type of straggler floc, if any, remains in the supernatant liquor above the main sludge mass.

The importance of conscientious, perceptive observation during the first five minutes can not be over emphasized. During these first five minutes the operator will acquire additional insight into sludge character and quality, and will be in a much better position to evaluate what the settlometer test reveals.

The sixty-minute reading is the second most important observation. It provides a check on final clarifier sludge blanket characteristics and is used to compute process equilibrium indices and operational control adjustment requirements.

After the tests are completed, the settlometers should remain undisturbed for at least four hours. The time at which previously compacted sludge starts to swell and rise to the surface is another important indicator of sludge quality. Settled sludge should not remain down forever, any more than it should gasify and pop to the surface during the sixty-minute test cycle. Well-oxidized sludge will frequently begin to swell somewhat after ninety minutes and will usually float to the surface within two to four hours after the test was started.

A portion of the sample collected for the settlometer test should be saved for solids determinations.

CENTRIFUGE TESTS

The centrifuge permits rapid determination of mixed liquor and return sludge solids concentrations for immediate use in calculating solids distribution ratios, effective return sludge percentages, solids concentration rates, clarifier sludge detention times, and a host of other process relationships used to determine operational control demands.

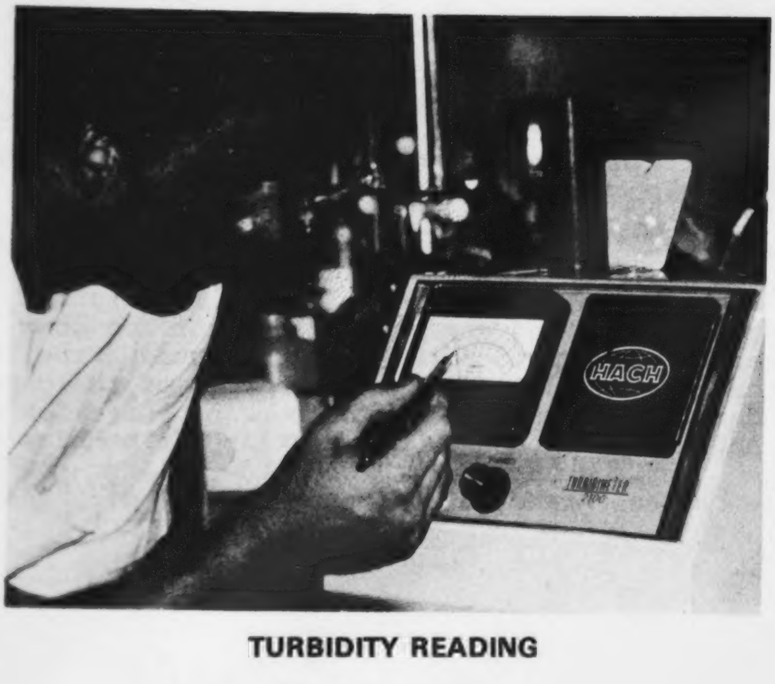
The use of 12.5 ml API (American Petroleum Institute) centrifuge tubes in a clinical centrifuge, with a six place horizontal head, revolving at full speed (position 7 on the International No. 428, for example) has been found convenient and appropriate for sewage plant control testing. The mixed liquor and return sludge specimens should be centrifuged for a standardized fifteen minute interval to assure consistent compaction and to avoid discrepancies that can be introduced by slight variations in testing time when shorter intervals (say from one to three minutes) are used. Shorter time intervals may be used for "trim spins" and other special tests when many specimens are centrifuged to determine the solids balance in multiple aeration tanks or clarifiers.

The centrifuge is an exceedingly useful and convenient tool for searching out and correcting unbalanced sewage or return sludge flow distribution as well as unequal mixed liquor and return sludge solids concentrations in multiple tank plants. It has also been used effectively to determine return sludge percentages in the all too many cases where flow meters have been missing or were in error. Mixed liquor and return sludge concentration data frequently are plugged into the mixing formulas, described in Part IIIA. It is then possible to determine either the primary effluent flow rate into the aeration tanks or the sludge withdrawal rate from the final clarifiers when either of the meters for these two locations is missing or inoperative.

Some operators question the use of the centrifuge for sludge concentration determination because such tests results can not always be correlated with suspended solids determinations by the laboratory balance. The variation in the ratio of mixed liquor suspended solids concentration determined by the laboratory balance to that determined by

PROPER SAMPLE HANDLING FOR TURBIDITY TEST

CENTRIFUGED SLUDGE SAMPLES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TURBIDITY READING

the centrifuge is affected by sludge age and oxidation and is, therefore, one of the virtues of the centrifuge test; not a defect. Furthermore, the centrifuge test result, because it is influenced by the specific gravity and the surface area of the sludge mass, provides a realistic measure of effective sludge concentration.

EFFLUENT TURBIDITY TESTS

Two turbidity determinations should be made on the sample collected from the final clarifier. A photo-electric activated readout type turbidimeter with results expressed in Jackson Turbidity Units (JTU) or Formazin Turbidity Units (FTU) is recommended. The turbidity of excellent final effluents usually ranges between 1.0 and 3.0 JTU. Final effluent turbidities greater than 3.0, and especially those exceeding 10.0 JTU, indicate that the full purification capability of the activated sludge process has not been achieved.

The first turbidity determination should be made shortly after the settlometer and centrifuge tests have been started. The sample should be stirred (only for the first test) before it is poured into the turbidimeter test vial. The vial exterior should always be wiped clean and dry before insertion into the turbidimeter. This precaution will protect the internal components and enhance accuracy.

The final effluent sample should then be put aside for a one-hour settling period to permit gravity separation of extraneous floatable scums and settleable solids that may be attributed to flow overloads or inappropriate final clarifier features. At the end of this time interval, the turbidity of the subnatant liquor in the settled final effluent sample should be determined.

Special additional precautions should be observed while pouring the "settled" specimens into the turbidimeter test vial. The specimen container should be carefully lifted from the work bench and any accumulated surface scum should be poured to waste before the settled liquid (free from any sludge that may have settled to the bottom of the container) is poured into the test vial. The pouring operation must be gradual and continuous to avoid creating air bubbles and to eliminate surface scums or settled solids that might otherwise cause erroneous interpretation of the test results.

When performed properly, the turbidity test will reflect process performance. If the final effluent contains excessive suspended solids, for example, differences in the turbidity test results on settled versus unsettled effluent specimens will indicate whether the problem was created by improper process control, hydraulic overloads or by defective final clarifiers. In other words, if the final clarifiers lack scum baffles and skimmers or have inappropriately placed final effluent launders, or if the tank geometry induces unnecessary velocity currents, the turbidity of the settled specimen will reveal the true effect of control adjustments on sludge characteristics and process equilibrium. Many times the final effluent produced by good sludge at proper process equilibrium contains unnecessarily high concentrations of solids that are needlessly forced out of the clarifiers by inappropriate or malfunctioning equipment. The object of this turbidity test is to define process response and control requirements rather than to document built-in, and usually not immediately correctable, plant defects.

Turbidimeter calibration and use should follow manufacturer's instructions. Where multiple turbidity standards are supplied with the equipment, the turbidimeter should be calibrated with the standard closest to the anticipated effluent turbidity. If, for example, 1.0, 10.0, and 100.0 FTU standards were provided, and the equipment had been calibrated with the 100 FTU standard, but the effluent turbidity read out at less than 10 FTU; the meter should be recalibrated with the 10 FTU standard and reread.

DISSOLVED OXYGEN TESTS

At least once per day, and preferably once during each eight hour shift, dissolved oxygen concentrations should be determined at the inlet and at the outlet ends of each "pass" or compartmented area of the aeration tanks. Additional dissolved oxygen determinations should be made more frequently at "one" or "a single" aeration tank sampling station to reveal dissolved oxygen variations throughout each 24-hour cycle. These additional tests usually are run once every four hours and should be scheduled to include the intervals when influent loads increase in the early afternoon and decrease in the early morning hours. A battery-operated dissolved oxygen field probe is much more convenient to use and provides more accurate mixed liquor DO values than the Winkler Method.

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EQUIVALENTS USED FOR ACTIVATED SLUDGE CALCULATIONS

ft x 0.3048 = m
inches x 2.540 = cm
m x 3.28083 = ft
m x 39.37 = in

sq ft x 0.0929 = sq m
sq m x 10.7639 = sq ft

cu ft x 28.3170 = liter
cu ft x 0.028317 = cu m
cu ft x 7.48052 = gal
cu m x 1000.0 = liter
cu m x 35.3145 = cu ft
cu m x 264.179 = gal

gal x 3.785 = liter
gal x 0.003785 = cu m
liter x 0.26417 = gal
mgd x 3785 = cu m/day
cu m/day x 0.000264 = mgd

gpd/sq ft x 0.0408 = cu m/day/sq m
cu m/day/sq m x 24.51 = gpd/sq ft

lb x 0.453592 = kg
lb x 453.592 = g
kg x 2.20462 = lb
kg x 1000.0 = g

lbs/1000 cu ft x 16.0 = g/cu m
g/cu m x 0.0625 = lbs/1000 cu ft

cu ft (H_2O) x 62.4 = lb (H_2O)
gal (H_2O) x 8.345 = lb (H_2O)
liter (H_2O) x 1.000 = kg (H_2O)

lb/day = mgd x mg/l x 8.345
kg/day = cu m/day x mg/l /1000

lb = English SLU x (WCR*/1198)
kg = Metric SLU x (WCR/10)

English SLU = Metric SLU x 264.2
Metric SLU = English SLU x 0.003785

*WCR = sludge weight (mg/l)/centrifuged concentration (%)

EPA-330/9-74-001c

NATIONAL WASTE TREATMENT CENTER - CINCINNATI

OPERATIONAL CONTROL PROCEDURES FOR THE ACTIVATED SLUDGE PROCESS

PART III-A

CALCULATION PROCEDURES

by

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Director, National Waste Treatment Center
(formerly Waste Treatment Branch, National Field
Investigations Center - Cincinnati)

DECEMBER 1973
(Revised Nov.,1975)

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF WATER PROGRAM OPERATIONS

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FOREWORD

The National Waste Treatment Center (Cincinnati) is developing a series of pamphlets describing Operational Control Procedures for the Activated Sludge Process. This series, describing the "NWTC Procedures", will include Part I OBSERVATIONS, Part II CONTROL TESTS, Part III CALCULATION PROCEDURES, Part IV SLUDGE QUALITY, Part V PROCESS CONTROL and an APPENDIX. Each of these individual parts will be released for distribution as soon as it is completed, though not necessarily in numerical order. The original five-part series may then be expanded to include case histories and refined process evaluation and control techniques.

This pamphlet has been developed as a reference for Activated Sludge Plant Control lectures I have presented at training sessions, symposia, and workshops. It is based on my personal conclusions reached while directing the operation of dozens of different activated sludge plants. This pamphlet is not necessarily an expression of Environmental Protection Agency policy or requirements.

The mention of trade names or commercial products in this pamphlet is for illustrative purposes and does not constitute endorsement or recommendation for use by the Environmental Protection Agency.

Alfred W. West

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DATA SOURCES AND TEXT ORGANIZATION

Calculation procedures used by the Waste Treatment Branch of the National Field Investigations Center - Cincinnati (NFIC-C) during technical assistance projects are described in this Part III of the Operational Control Procedures for the Activated Sludge Process. The suggested types and frequency of observations and control tests have been described in Parts I and II.

Essential flow data, such as waste water flow into the aeration tanks (AFI), return sludge flow (RSF), excess sludge wasted from the process (XSF), etc., are determined from the plant flow meters at each test period. Sludge and process characteristics, such as mixed liquor and return sludge concentrations (ATC and RSC), settled sludge volume (SSV), depth of sludge blanket in the final clarifier (DOB), etc., are determined by the control tests that have been described in Part II CONTROL TESTS.

These readings and control test results comprise the "Observed:" data that are entered in the formulas to determine the "Wanted:" information. Formulas and calculation examples are provided in this Part. The procedures for using these calculated values to evaluate sludge quality and process status, and to determine control adjustment requirements are described in subsequent Parts.

All calculations are performed in step-by-step fashion even though, in some cases, the end result could have been determined by one longer equation containing all the variables. This step-by-step method is preferred because some of the intermediate results are informative in themselves and are frequently used directly in other equations to calculate other process relationships. All examples are expressed in both metric and English units and a table of equivalents is printed inside the front cover. Figure 1 identifies tank sizes, flow rates and sludge concentrations used in the calculation examples. A complete list of all symbols and their definitions is included in the APPENDIX to this series. For convenient referencing, each calculation example is preceded by definitions of the symbols used in the example.

Some sections also include brief discussions of certain implicit assumptions, approximations, and use of the computed relationships. It is hoped that such statements will help clarify and add realism, even though they may be repeated and expanded in subsequent Parts describing process

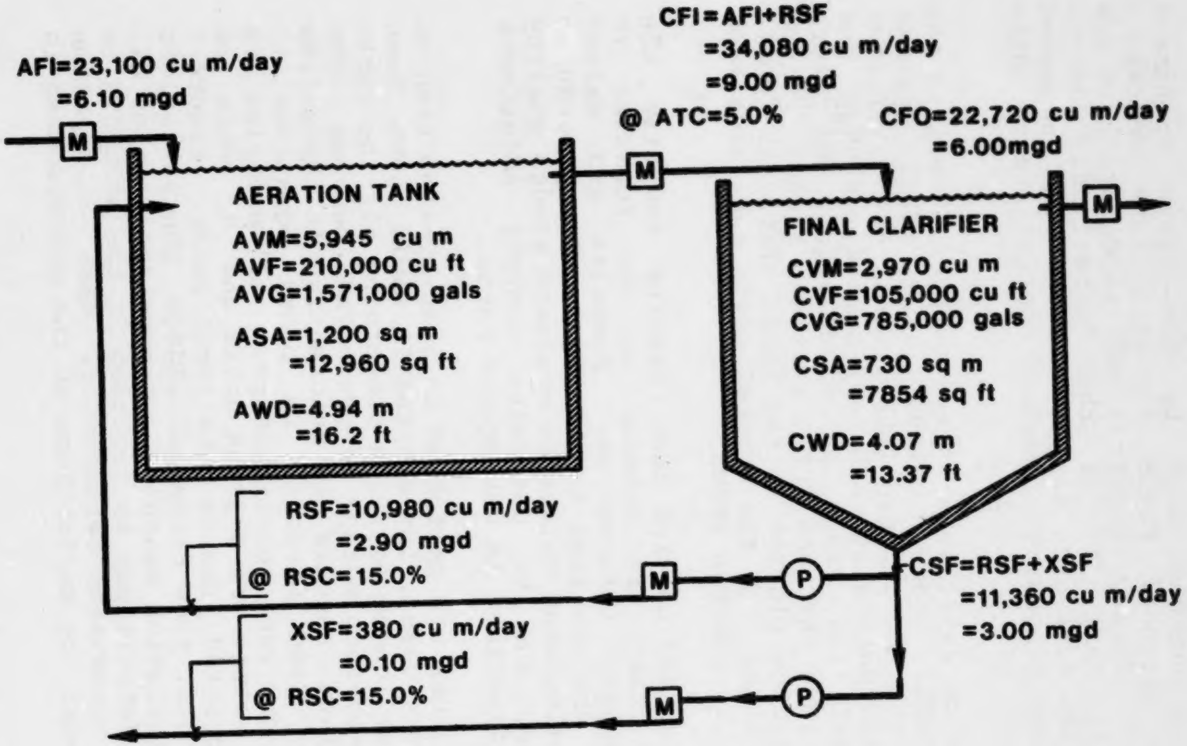

AFI=23,100 cu m/day
=6.10 mgd
M
AERATION TANK
AVM=5,945 cu m
AVF=210,000 cu ft
AVG=1,571,000 gals
ASA=1,200 sq m
=12,960 sq ft
AWD=4.94 m
=16.2 ft
CFI=AFI+RSF
=34,080 cu m/day
=9.00 mgd
@ ATC=5.0%
M
CFO=22,720 cu m/day
=6.00mgd
M
FINAL CLARIFIER
CVM=2,970 cu m
CVF=105,000 cu ft
CVG=785,000 gals
CSA=730 sq m
=7854 sq ft
CWD=4.07 m
=13.37 ft
CSF=RSF+XSF
=11,360 cu m/day
=3.00 mgd
P
M
RSF=10,980 cu m/day
=2.90 mgd
@ RSC=15.0%
P
M
XSF=380 cu m/day
=0.10 mgd
@ RSC=15.0%

Figure 1

ACTIVATED SLUDGE SYSTEM
Volumes, Flows, and Sludge
Concentrations Used in the Examples

evaluation and control. Finally, the development of the mixing formulas and clarifier sludge flow demand formula are included in the last section of this Part for those who may be interested in their derivation.

Though the size of Part III may appear formidable, most calculations, except those in Part III B - Step Aeration and Contact Stabilization, are quite simple and straightforward.

Most of these routine process relationship calculations that are based on the sludge unit concept were proposed originally by E.B. Mallory. Some of the process loading factors and purification pressures presented reflect contemporary reaction kinetics principles.

The clarifier sludge flow demand formula (CSFD) and the associated sludge concentration ratio (SCR) and sludge weight-to-concentration ratio (WCR) that are used to calculate process control adjustment requirements were evolved by the author. He also developed the coordinated testing, calculation, evaluation and control procedures - "NFIC-C Procedures" - described in this pamphlet series.

ACTIVATED SLUDGE CHARACTERISTICS

ACTIVATED SLUDGE CONCENTRATIONS

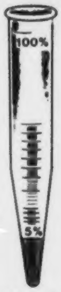
ATC & RSC

Sludge concentration values used for calculating process relationships and control requirements are determined by the centrifuge test that is described in Part II, CONTROL TESTS.

Mixed liquor (ATC) and return sludge (RSC) concentrations are the most frequently used centrifuge values. These symbols are defined as follows:

ATC = Aeration Tank Concentration

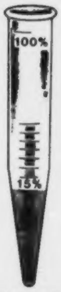
The mixed liquor concentration determined by the standard 15-minute centrifuge test, expressed as the percent of the centrifuge tube occupied by the compacted mixed liquor sludge.



ATC=5%

RSC = Return Sludge Concentration

The return sludge concentration determined by the standard 15-minute centrifuge test, expressed as the percent of the centrifuge tube occupied by the compacted return sludge.



RSC=15%

SLUDGE WEIGHT-TO-CONCENTRATION RATIO - WCR

WCR = MLTSS/ATC

Mixed liquor concentration, expressed in percent and identified as ATC, should be determined by the standard centrifuge test during every control test period. At least once every 24 hours the weight of mixed liquor total suspended solids, expressed in mg/l and identified as MLTSS, should be determined by the laboratory balance from a portion of one of the samples that had been used to measure ATC.

Though the solids concentration by centrifuge is used for most process control calculations discussed in these pamphlets, the ratio of solids by weight to solids by centrifuge (WCR) is one of the factors used to evaluate sludge oxidation and relative age.

SYMBOLS

ATC = Aeration Tank Concentration (%)
MLTSS = Mixed Liquor Total Suspended Solids, In mg/l, by laboratory balance.
WCR = Sludge Weight-to-Concentration Ratio

EXAMPLES

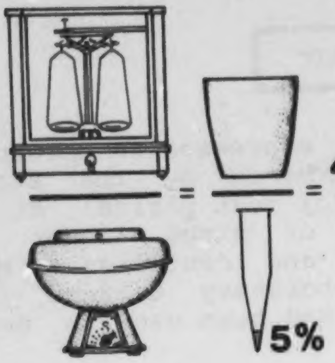
Observed:

	"Young" Sludge	"Normal" Sludge	"Old" Sludge
MLTSS =	4,000 mg/l	4,000 mg/l	4,000 mg/l
ATC =	8.0%	5.0%	4.0%

Wanted: WCR

Therefore:

	"Young" Sludge	"Normal" Sludge	"Old" Sludge
WCR =	MLTSS/ATC	MLTSS/ATC	MLTSS/ATC
=	4,000/8	4,000/5	4,000/4
=	500	800	1,000



$$= \frac{4{,}000\ \text{mg/l}}{5.0\%} = 800 = \text{WCR}$$

The WCR of a properly oxidized sludge will usually approximate 800. The WCR for a young sludge will usually be less than 600, and that for an old, or over-oxidized, sludge may exceed 1,000.

The above examples also demonstrate that there is no one common constant to convert ATC to MLTSS for all types of sludges.

SLUDGE UNITS - SLU

SLU = Volume X Centrifuged Concentration/100

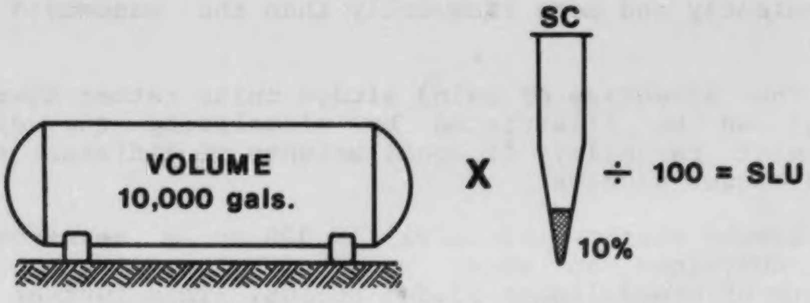
The number of sludge units in any tank, or portion of any tank or container, is determined by multiplying the volume occupied by the sludge (measured in cubic meters or gallons) times the sludge concentration (measured by the centrifuge test), but divided by 100 to convert the observed percent concentration to a decimal fraction).

SYMBOLS

SC = Sludge Concentration (% by centrifuge)
*SLU = Sludge Units

* Subscripts are not needed to distinguish between Metric or English sludge units because the type of SLU will obviously conform to the system (Metric or English) used by the operator.

Formulas to convert sludge units to pounds or kilograms and to convert Metric sludge units to English sludge units are included in the Equivalents Table inside the front cover.



10,000 gals. X 10.0 ÷ 100 = 1,000 SLU

EXAMPLES

Metric Units

Observed:

Volume = 5,945 cu m
SC = 5.0%

Wanted: SLU

Therefore:

SLU = cu m x SC/100
= 5,945x5.0/100
= 297 SLU

English Units

Observed:

Volume = 1,571,000 gals
SC = 5.0%

Therefore:

SLU = gals x SC/100
= 1,571,000x5.0/100
= 78,550 SLU

DISCUSSION

The sludge unit, which is based on the centrifuge test, rather than the mass unit (expressed by weight - in kilograms or pounds) which is determined by the laboratory balance, is used for most process relationship calculations. This is because many properties that govern the sludge's purification capability also influence its compressibility and the end point concentration in the centrifuge tube. Additionally, the centrifuge test, which is also used to calculate WCR, is more rapid, and can be performed conveniently and more frequently than the suspended solids test.

The advantage of using sludge units rather than sludge weight can be illustrated by visualizing the different treatment capability of equal weights of different types of mixed liquor sludges.

Assume that two identical 10,000 cu m aeration tanks each contained an equal weight, but a different type or quality of mixed liquor sludge solids. Then further assume that Tank #1 contained a properly oxidized, highly active, flocculant sludge with a large percentage of voids and surface area. Let's also assume that the measured sludge concentration, by weight, was 2,400 mg/l. An adsorptive sludge of this type would have a WCR of about 800 and the ATC by centrifuge would have approximated 3.0%.

Then for Tank #1:

SLUDGE WEIGHT = cu m x mg/l / 1,000

= 10,000x2,400/1,000 = 24,000 kg

SLUDGE UNITS = cu m x ATC/100

= 10,000x3.0/100 = 300 SLU

Now let's assume that Tank #2 contained an over-oxidized less active, older, slightly knotted, dense floc that settled more rapidly but had less adsorptive capacity. And assume that the sludge concentration, by weight, also equaled 2,400 mg/l. A sludge of this type would have a WCR of about 1,200 and the ATC by centrifuge would have approximated 2.0%.

Then for Tank #2:

SLUDGE WEIGHT = 10,000 x 2,400/1,000 = 24,000 kg

SLUDGE UNITS = 10,000 x 2.0/100 = 200 SLU

If evaluated on the basis of weight alone, it would have appeared that both tanks provided equal purification capabilities. (2,400 mg/l and 24,000 kgs in each tank). But from an evaluation of sludge units it is evident that the first tank (300 SLU) contained 50% more sludge units than the second tank (200 SLU). Although the highly active sludge in the first tank would probably not perform 50% more work than the equal weight of less active and poorer quality sludge in the second tank, it certainly could produce a significantly better quality final effluent.

No similar comparison is made with an exceptionally young, fluffy, slowly settling bulking sludge since, in actual practice, such a sludge could not be held in the system. The WCR might be 300 and the centrifuged ATC of a 2,400 mg/l mixed liquor would equal 8.0%. Such a slowly settling sludge, though capable of producing a sparkling settlometer supernatant, would be washed out of the final clarifier long before ATC could be increased to the 8.0% level.

In summary, the sludge unit data would have indicated the potential superiority of sludge in the first tank, while the mass data, based on weight alone, would have erroneously indicated that the treatment capability of both sludges was equal.

SETTLED SLUDGE CONCENTRATION - SSC

$$\boxed{SSC = 1{,}000 \times ATC/SSV}$$

Settled sludge concentration (SSC) values are calculated from the centrifuged mixed liquor concentration (ATC) and the settled sludge volume (SSV) values that are observed during the 60 minute settlometer test. Sludge quality, as determined by both the shape of the SSC curve and the 60 minute SSC value is discussed in PART IV SLUDGE QUALITY.

A table of calculated SSC values and the SSV and SSC curves are illustrated in the following example and in Figure 2.

SYMBOLS

ATC = Aeration Tank Concentration (%)
SSC = Settled Sludge Concentration (%)
SST = Sludge Settling Time (minutes)
SSV = Settled Sludge Volume (cc/l in settlometer)

EXAMPLE

Observed:

ATC = 3.0%
SSV = Values shown in Table 1.

Wanted: SSC Trend during the 60-minute test

Therefore:

TABLE 1.

ELAPSED TIME SST (min.)	OBSERVED SSV (cc/l)	SSC = 1000 ATC/SSV		CALCULATED SSC (%)
0	1000	3000/1000	=	3.00
5	630	3000/630	=	4.76
10	470	3000/470	=	6.38
15	390	3000/390	=	7.69
20	340	3000/340	=	8.82
25	300	3000/300	=	10.00
30	275	3000/275	=	10.91
40	235	3000/235	=	12.76
50	215	3000/215	=	13.95
60	200	3000/200	=	15.00

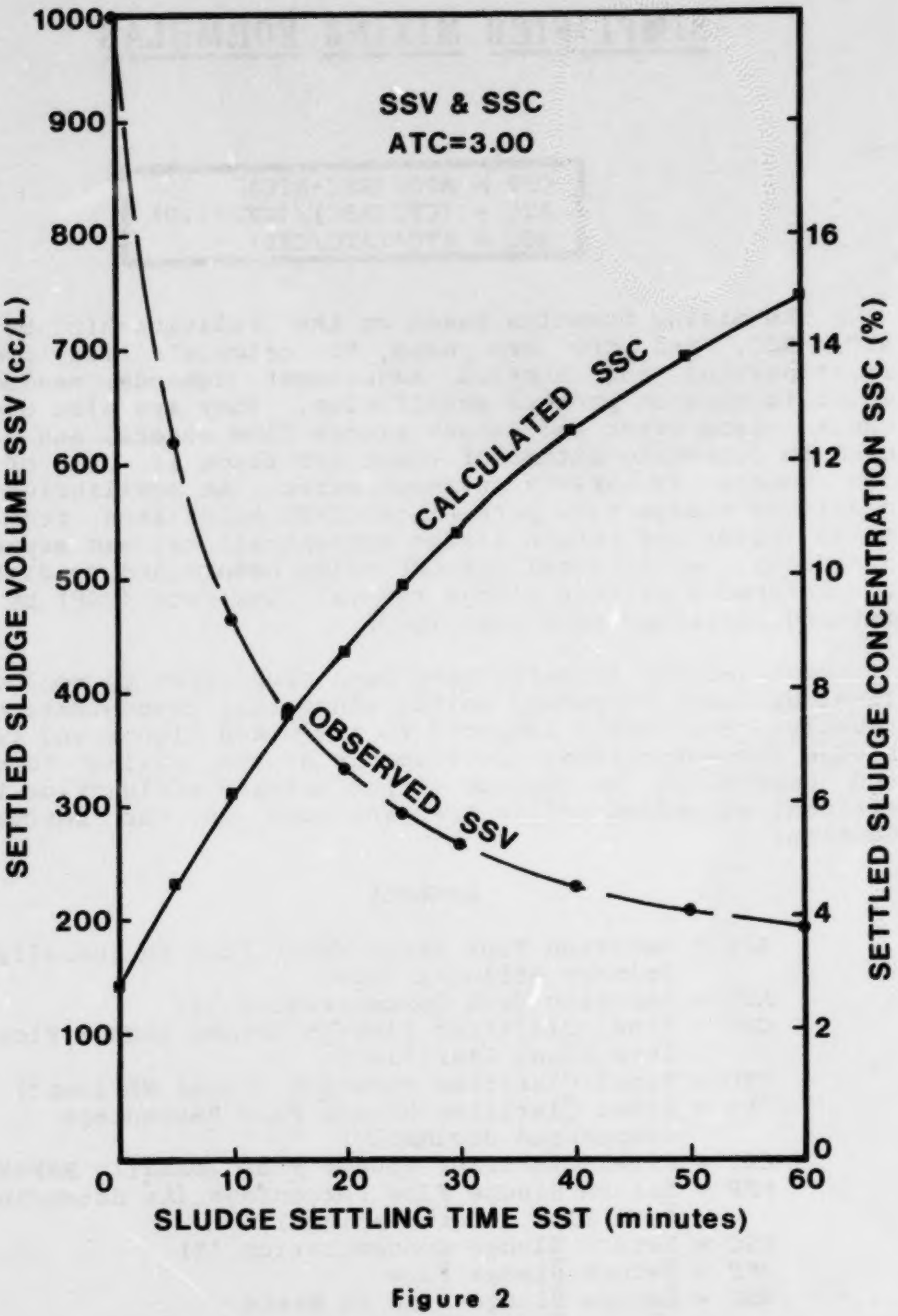


Figure 2

SLUDGE SETTLING AND CONCENTRATION VS. TIME

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SIMPLIFIED MIXING FORMULAS

$$\boxed{\begin{aligned}\text{CFP} &= \text{ATC}/(\text{RSC}-\text{ATC})\\ \text{ATC} &= (\text{CFP}\text{X}\text{RSC})/(\text{CFP}+1.0)\\ \text{RSC} &= \text{ATC}+(\text{ATC}/\text{CFP})\end{aligned}}$$

The mixing formulas based on the relationship between ATC, RSC, and CFP are used to calculate many process relationships and control adjustment demands needed to maintain optimum process equilibrium. They are also used to check waste water and return sludge flow meters, and can be used to determine either of these two flows if one of the two meters is missing or inoperative. At equilibrium, the clarifier sludge flow percentage (CFP) calculated from the mixed liquor and return sludge concentrations, and expressed decimally, will equal the CFP value determined by dividing the metered clarifier sludge removal flow rate (CSF) by the metered clarifier flow rate (CFO).

The mixing formulas have been simplified by neglecting final effluent suspended solids since that concentration is usually very small compared to the mixed liquor and return sludge concentrations. Development of the mixing formulas and expansions to include either primary effluent or final effluent suspended solids are included in the Derivation Section.

SYMBOLS

AFI = Aeration Tank Waste Water Flow-In (Usually primary effluent flow)
ATC = Aeration Tank Concentration (%)
CFI = Final Clarifier Flow-In (Mixed liquor Flow into Final Clarifier)
CFO = Final Clarifier Flow-Out (Final Effluent)
CFP = Final Clarifier Sludge Flow Percentage (Expressed decimally)
CSF = Final Clarifier Sludge Flow (Usually RSF+XSF)
RFP = Return Sludge Flow Percentage (As determined from flow meter readings)
RSC = Return Sludge Concentration (%)
RSF = Return Sludge Flow
XSF = Excess Sludge Flow to Waste

CFP EXAMPLES

CFP = ATC/(RSC-ATC)

To illustrate use of the CFP formula let's assume that the return sludge flow (RSF) meter failed and was taken out of service. In this case, the aeration tank flow-in (AFI) meter and the excess sludge flow to waste meter (XSF) were functioning and the operator could therefore calculate the return sludge flow and other needed process relationships from the ATC and RSC test data.

The measured flows and those flows calculated from the CFP formula are shown in Figure 3 and the calculation examples follow.

Metric Units

Observed:

AFI = 23,100 cu m/day
XSF = 380 cu m/day
ATC = 5.0%
RSC = 15.0%

Wanted: CFP, CSF, RSF & RFP

Therefore:

CFP = ATC/(RSC-ATC)
= 5.0/(15.0-5.0)
= 0.50
or 50%

CFO = AFI-XSF
= 23,100-380
= 22,720 cu m/day

CSF = CFOxCFP
= 22,720x0.50
= 11,360 cu m/day

RSF = CSF-XSF
= 11,360-380
= 10,980 cu m/d

English Units

Observed:

AFI = 6.100 mgd
XSF = 0.100 mgd
ATC = 5.0%
RSC = 15.0%

Therefore:

CFP = ATC/(RSC-ATC)
= 5.0/(15.0-5.0)
= 0.50
or 50%

CFO = AFI-XSF
= 6.100 - 0.100
= 6.000 mgd

CSF = CFOxCFP
= 6.000x0.50
= 3.000 mgd

RSF = CSF-XSF
= 3.000-0.100
= 2.900 mgd

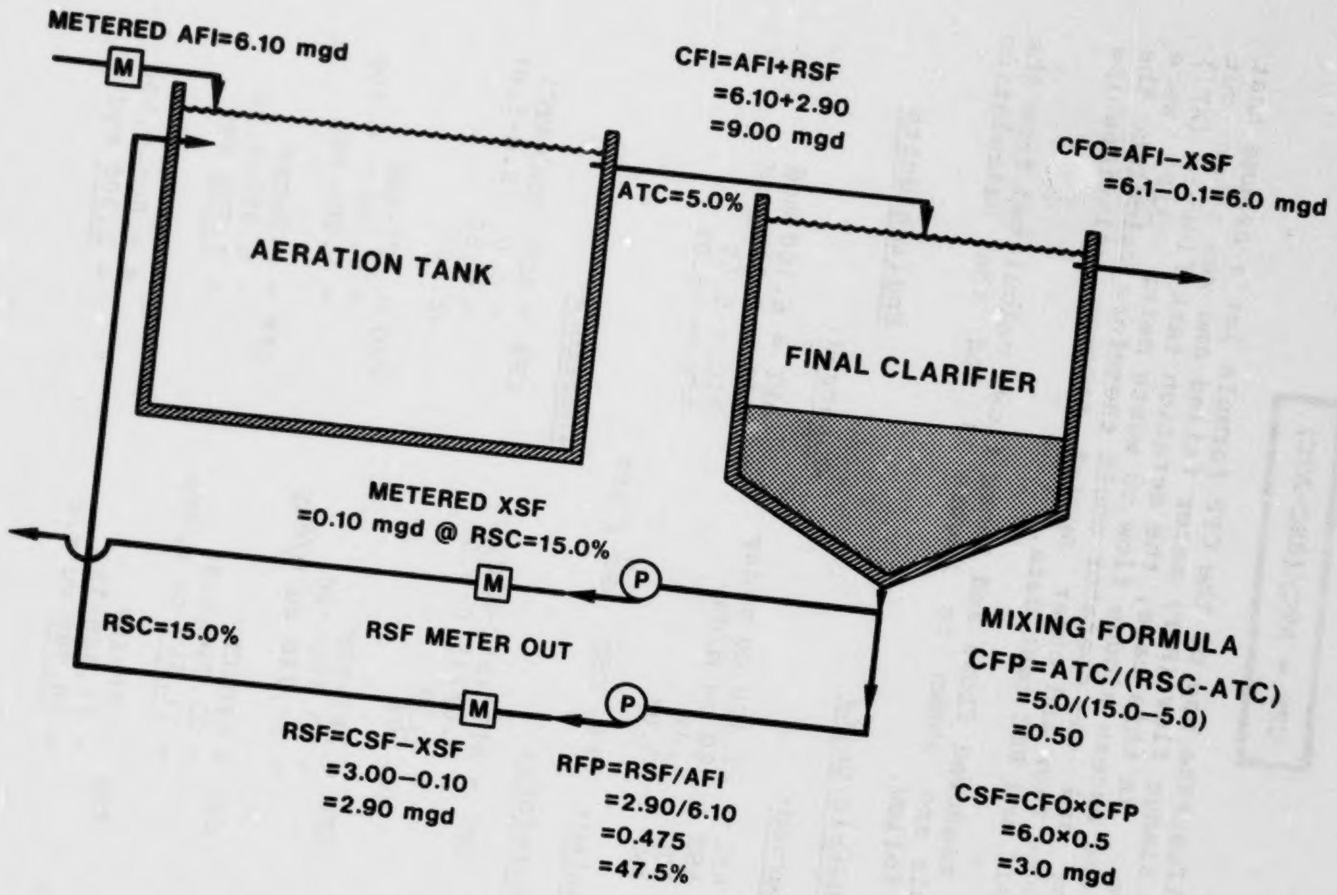

METERED AFI=6.10 mgd
M
CFI=AFI+RSF
=6.10+2.90
=9.00 mgd
CFO=AFI−XSF
=6.1−0.1=6.0 mgd
ATC=5.0%
AERATION TANK
FINAL CLARIFIER
METERED XSF
=0.10 mgd @ RSC=15.0%
M
P
RSC=15.0%
RSF METER OUT
M
P
RSF=CSF−XSF
=3.00−0.10
=2.90 mgd
RFP=RSF/AFI
=2.90/6.10
=0.475
=47.5%
MIXING FORMULA
CFP=ATC/(RSC-ATC)
=5.0/(15.0−5.0)
=0.50
CSF=CFO×CFP
=6.0×0.5
=3.0 mgd

Figure 3

CFP MIXING FORMULA USED TO DETERMINE UNKNOWN FLOWS.

RFP = RSF/AFI	RFP = RSF/AFI
= 10,980/23,100	= 2.900/6.100
= 0.475	= 0.475
or 47.5%	or 47.5%

ATC EXAMPLES

$$\boxed{ATC = (CFP \times RSC)/(CFP+1.0)}$$

In this case assume that the maximum capacity of the final clarifier sludge removal pump was 11,360 cu m/day (3.000 mgd) and the waste water flow into the aeration tanks (AFI) averaged 22,720 cu m/day (6.000 mgd) when sludge wasting was cut back to zero.

Furthermore, the mixed liquor could concentrate to an SSC of 15% after one hour in the Settlometer.

Then further assume that the operator wanted to know the maximum mixed liquor concentration (ATC) his process could maintain at equilibrium if he controlled his return sludge concentration (RSC) to equal the one hour SSC of 15%.

These conditions are illustrated in Figure 4 and the calculations follow.

Metric Units	English Units
Observed:	Observed:
AFI = 22,720 cu m/day	AFI = 6.000 mgd
CFO = AFI	CFO = AFI
CFO = 22,720 cu m/day	CFO = 6.000 mgd
XSF = 0.0	XSF = 0.0
CSF = 11,360 cu m/day	CSF = 3.000 mgd
RSC = 15%	RSC = 15%

Wanted: ATC at process equilibrium.

Metric Units	English Units
Therefore:	Therefore:
CFP = CSF/CFO	CFP = CSF/CFO
= 11,360/22,720	= 3.00/6.00
= 0.50	= 0.50

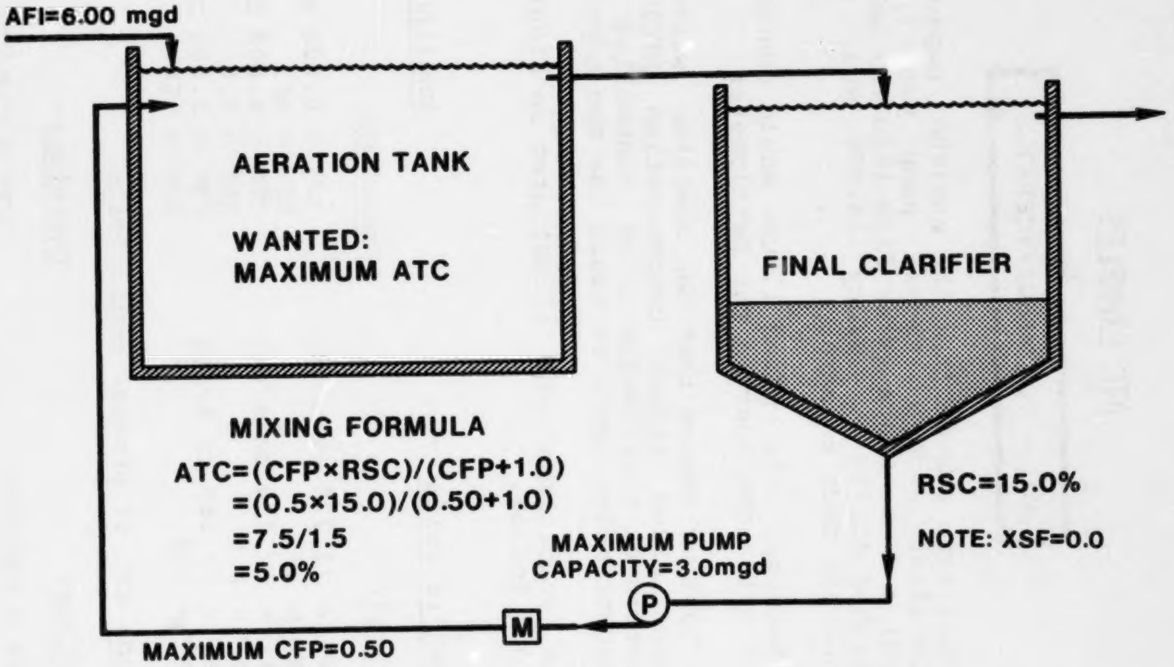

AFI=6.00 mgd
AERATION TANK
WANTED:
MAXIMUM ATC
FINAL CLARIFIER
MIXING FORMULA
ATC=(CFP×RSC)/(CFP+1.0)
=(0.5×15.0)/(0.50+1.0)
=7.5/1.5
=5.0%
RSC=15.0%
NOTE: XSF=0.0
MAXIMUM PUMP
CAPACITY=3.0mgd
P
M
MAXIMUM CFP=0.50

Figure 4

ATC MIXING FORMULA USED TO DETERMINE MAXIMUM ATC

ATC = (CFPxRSC)/(CFP+1.0)
= (0.5x15)/(0.5+1.0)
= 7.5/1.5
= 5.0%

ATC = (CFPxRSC)/(CFP+1.0)
= (0.5x15)/(0.5+1.0)
= 7.5/1.5
= 5.0%

If sludge quality remained the same, the clarifier sludge pumping capacity would permit building ATC up to 5.0% while maintaining process equilibirum.

RSC EXAMPLES

RSC = ATC + (ATC/CFP)

In this case let's assume that the operator, who had been collecting clarifier sludge samples from near the surface of the pump station wet well, suspected that the solids content of these samples did not truly represent the solids content of the return sludge being pumped to the aeration tanks. He suspected solids-liquid separation in the deep wet well and therefore feared that the concentration of return sludge pumped from the bottom of the wet well might be greater than the measured 10.0% RSC of the sludge sample collected near the wet well surface.

He could check this out a number of ways, and one would be by use of the RSC mixing formula.

The plant conditions are illustrated in Figure 5 and the calculation examples follow:

Metric Units

Observed:

CFI = 34,080 cu m/day
CSF = 11,360 cu m/day
XSF = 0.0
ATC = 5.0%

Wanted: RSC

Therefore:

CFO = CFI-CSF
= 34,080-11,360
= 22,720 cu m/day

English Units

Observed:

CFI = 9.000 mgd
CSF = 3.000 mgd
XSF = 0.0
ATC = 5.0%

CFO = CFI-CSF
= 9.000-3.000
= 6.000 mgd

CFP = CSF/CFO
= 11,360/22,720
= 0.50

RSC = ATC + (ATC/CFP)
= 5.0 + (5.0/0.5)
= 15.0%

CFP = CSF/CFO
= 3.000/6.000
= 0.50

RSC = ATC + (ATC/CFP)
= 5.0 + (5.0/0.5)
= 15.0%

The operator would now know that the RSC should actually have approximated 15 instead of 10 percent. He would then relocate his return sludge sampling point to the sludge flow discharge channel or to some other location where a truly representative sample could be collected.

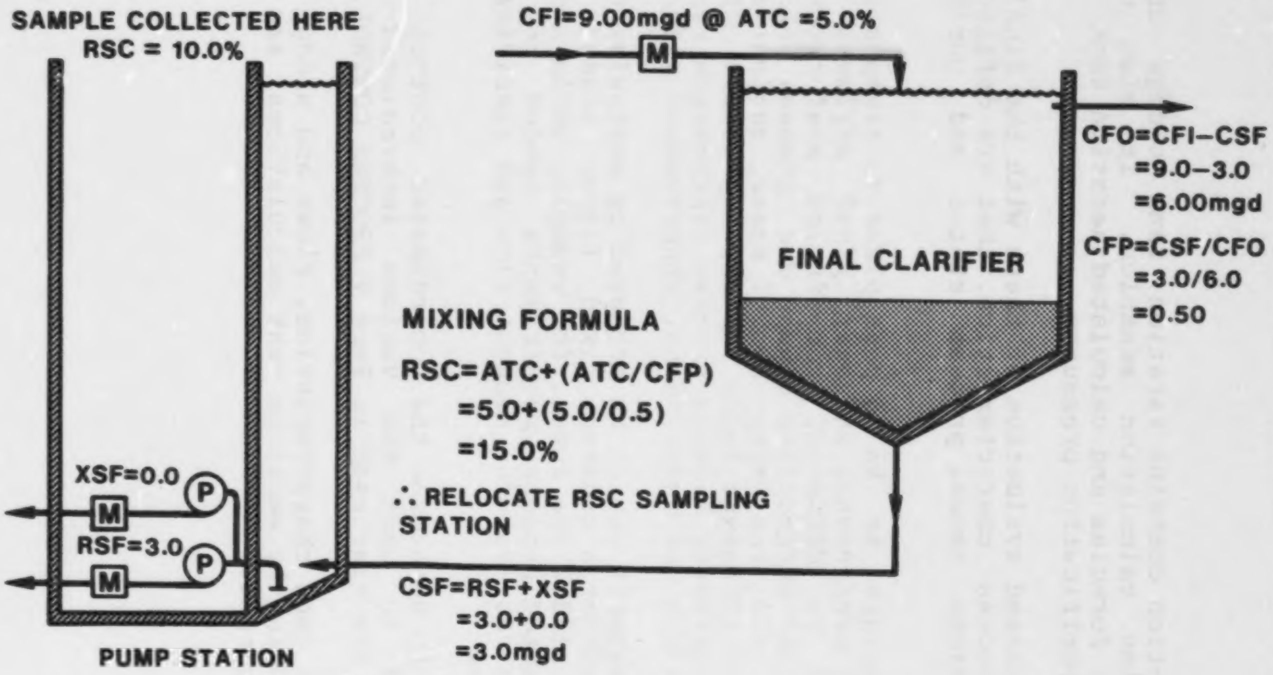

SAMPLE COLLECTED HERE
RSC = 10.0%
CFI=9.00mgd @ ATC =5.0%
M
FINAL CLARIFIER
CFO=CFI−CSF
=9.0−3.0
=6.00mgd
CFP=CSF/CFO
=3.0/6.0
=0.50
MIXING FORMULA
RSC=ATC+(ATC/CFP)
=5.0+(5.0/0.5)
=15.0%
∴ RELOCATE RSC SAMPLING STATION
XSF=0.0
RSF=3.0
P
M
CSF=RSF+XSF
=3.0+0.0
=3.0mgd
PUMP STATION

Figure 5

RSC MIXING FORMULA USED TO
CHECK VALIDITY OF RSC TEST RESULTS

AERATION TANK CHARACTERISTICS

This section contains aeration tank sludge unit and detention time calculation examples. It also contains supplementary formulas and calculated aeration tank loading factors and purification pressures.

A coordinated evaluation of these with the final clarifier and process characteristics, that are defined in the next two Sections, reveal process status and purification potential.

This appears to be a good place to reemphasize that optimum plant performance and best final effluent quality are achieved by diligent, coordinated evaluation of all interrelated and interacting sludge and process characteristics. In all too many actual cases, activated sludge plants produce effluents below the quality level they are capable of achieving because process adjustments were aimed at meeting only a few independent, preconceived objectives.

Best treatment cannot be achieved by exclusive attempts to maintain either a constant mixed liquor sludge concentration or sludge age level, for example, while neglecting other coordinated process requirements needed to satisfy such demands as return sludge flow and clarifier sludge detention time.

Methods to determine the coordinated control adjustments needed to meet the various interrelated process requirements are discussed in Part V PROCESS CONTROL.

Aeration tank characteristics, flows and sludge concentrations used in the aeration tank calculations are illustrated in Figure 6.

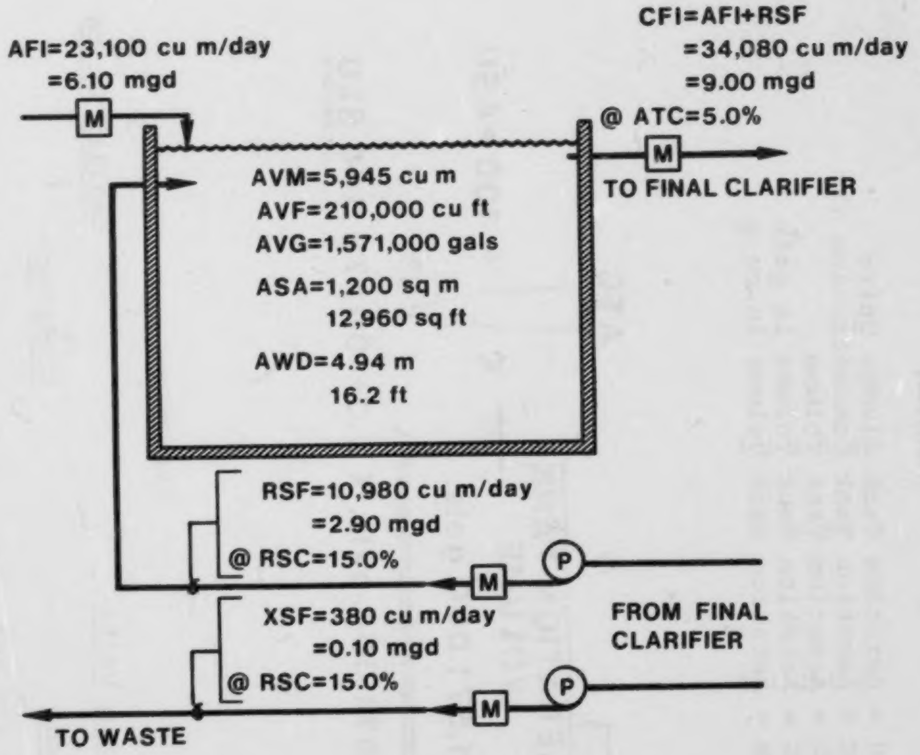

AFI=23,100 cu m/day
=6.10 mgd
M
CFI=AFI+RSF
=34,080 cu m/day
=9.00 mgd
@ ATC=5.0%
M
TO FINAL CLARIFIER
AVM=5,945 cu m
AVF=210,000 cu ft
AVG=1,571,000 gals
ASA=1,200 sq m
12,960 sq ft
AWD=4.94 m
16.2 ft
RSF=10,980 cu m/day
=2.90 mgd
@ RSC=15.0%
M
P
FROM FINAL
CLARIFIER
XSF=380 cu m/day
=0.10 mgd
@ RSC=15.0%
M
P
TO WASTE

Figure 6

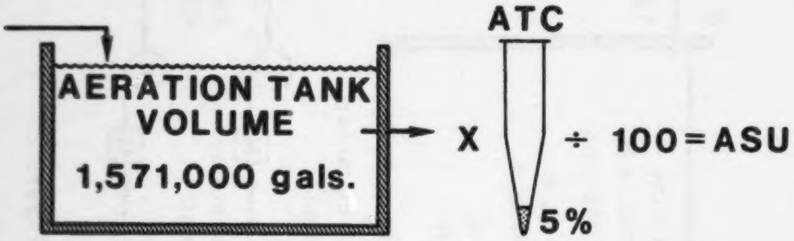
AERATION TANK
Volumes, Flows, and Sludge Concentrations
Used in the Examples

AERATION TANK SLUDGE UNITS - ASU

ASU = AVxATC/100

SYMBOLS

ASU = Aeration Tank Sludge Units
ATC = Aeration Tank Concentration (%)
AV = Aeration Tank Volume
AVG = Aeration Tank Volume in gals
AVM = Aeration Tank Volume in cu m



1,571,000 gals. X 5.0÷100=78,550 SLU

EXAMPLES

Metric Units

Observed:

AVM = 5,945 cu m
ATC = 5.0%

Wanted: ASU

Therefore:

ASU = AVMxATC/100
= 5,945x5.0/100
= 297

English Units

Observed:

AVG = 1,571,000 gals
ATC = 5.0%

Therefore:

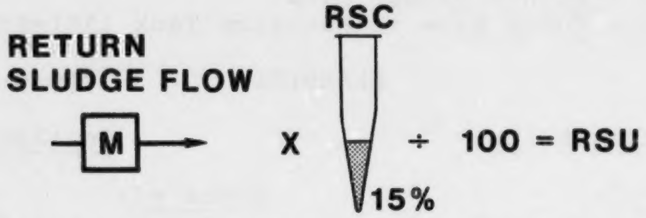
ASU = AVGxATC/100
= 1,571,000x5.0/100
= 78,550

RETURN SLUDGE UNITS - RSU

RSU = RSF x RSC/100

SYMBOLS

RSC = Return Sludge Concentration (%)
RSF = Return Sludge Flow
RSU = Return Sludge Units (to aeration tanks)



2,900,000 gals/day X 15.0÷100=435,000 RSU/day

EXAMPLES

Metric Units

Observed:

RSF = 10,980 cu m/day
RSC = 15.0%

Wanted: RSU

Therefore:

RSU = RSFxRSC/100
= 10,980x15/100
= 1650/day

English Units

Observed:

RSF = 2.900 mgd
RSC = 15.0%

Therefore:

RSU = RSFxRSC/100
= 2,900,000x15.0/100
= 435,000/day

AERATION TANK DETENTION TIME IN HRS - ADT

ADT@AFI = (AVx24)/AFI
ADT@TFL = (AVx24)/(AFI+RSF)

SYMBOLS

ADT = Aeration Tank Detention Time (hrs)
AFI = Aeration Tank Waste Water Flow-In (usually primary effluent flow)
AV = Aeration Tank Volume
AVG = Aeration Tank Volume in gals
AVM = Aeration Tank Volume in cu m
RSF = Return Sludge Flow
TFL = Total Flow to Aeration Tank (AFI+RSF)

EXAMPLES

Metric Units

Observed:

AVM = 5,945 cu m
AFI = 23,100 cu m/day
RSF = 10,980 cu m/day

Wanted: ADT@AFI & ADT@TFL

Therefore:

ADT@AFI = (AVMx24)/AFI
= (5,945x24)/23,100
= 6.18 hrs

ADT@TFL = (AVMx24)/(AFI+RSF)
= (5,945x24)/(23,100 +10,980)
= 4.19 hrs

English Units

Observed:

AVG = 1.571 million gal
AFI = 6.100 mgd
RSF = 2.900 mgd

Therefore:

ADT@AFI = (AVGx24)/AFI
= (1.571x24)/6.1
= 6.18 hrs

ADT@TFL = (AVGx24)/(AFI+RSF)
= (1.571x24)/(6.1+2.9)
= 4.19 hrs

ORGANIC LOADING AND PURIFICATION PRESSURES

AERATION TANK LOADING FACTORS

The following monitoring type BOD loading factors, that are calculated after the BOD test results are obtained, can be used to evaluate certain historical cause-and-effect relationships even though they cannot be used for day-to-day process control. Such factors, when related to actual plant performance, can be used to develop design criteria for future plant modifications and additions. (All symbols have been explained in previous sections.)

Metric Units	English Units
kg BOD/1000 AVM	lbs BOD/1000 AVF
kg BOD/ASU	lbs BOD/1000 ASU
kg BOD/kg MLVSS	lbs BOD/lb MLVSS

Similar calculations may be based on COD, TOC or other loading measurements.

RELATIVE PURIFICATION PRESSURES

When correlated with sludge quality, the following factors indicate process purification pressures. The first three factors can be determined rapidly after each control test. The last two factors, though more definitive, can only be calculated after the BOD test data are available.

This section only introduces additional factors, which when combined with other sludge quality indicators, can help the operator interpret process responses to control adjustments.

Metric Units	English Units
ATCxADT@AFI	ATCxADT@AFI
ATCxADT@TFL	ATCxADT@TFL
RSU/1000 cu m AFI	RSU/1000 gals AFI
ATCxADT@TFL/mg/l BODd	ATCxADT@TFL/mg/l BODd
RSU/kg of BODi	RSU/lb of BODi

All symbols except the following have been defined in previous sections.

BODi = Five-day biochemical oxygen demand of the waste water entering (in) the aeration tanks.
BODo = Five-day biochemical oxygen demand of the final clarifier effluent. (out)
BODd = Calculated net five-day biochemical oxygen demand of waste water and the "liquid portion" of the return sludge at the aeration tank entrance. (diluted waste water)
= (BODi+(BODoxRFP))/(1.0+RFP)

Except for the following BODd calculation, examples are not shown since all other intermediate calculations are those conventionally used by plant operators and the loading factors and purification pressure values are simple fractions of previously defined characteristics. Aeration tank detention times (ADT) are based on waste water flow alone (@AFI), or waste water flow plus return sludge flow (@TFL).

BODd EXAMPLE

BODd = (BODi+(BODoxRFP))/(1.0+RFP)
= (160+(10x0.475))/(1.0+0.475)
= 112 mg/l

Note: Return sludge usually contains less than 2.0% solids and the BOD 5 of the liquid portion (98%+ of the total return sludge flow) should therefore approximate the BOD 5 of the clarifier effluent. The entire return sludge flow, rather than the variable liquid fraction, is used to calculate BODd. This facilitates using normally available data directly rather than introducing additional required analyses and calculations. The logic is in line with some contemporary kinetics principles.

The following Metric and English unit results are included to permit checking the formulas and the examples given in previous pages.

Test Results	Metric Units	English Units
AFI	23,100 cu m/d	6.1 mgd
RSF	10,980 cu m/d	2.9 mgd
BODi	160 mg/l	160 mg/l
BODo	10 mg/l	10 mg/l
MLVSS	3000 mg/l	3000 mg/l
RSTSS	12,000 mg/l	12,000 mg/l
ATC	5.0%	5.0%
RSC	15.0%	15.0%
AV	5945 cu m	0.210 million cu ft
AV	5945 cu m	1.571 million gals
Results of Intermediate Calculations		
BODd	112 mg/l	112 mg/l
BODi	3,700 kg/day	8,140 lbs/day
ASU	297 SLU	78,550 SLU
MLVSS	17,835 kg	39,300 lbs
RSTSS	131,700 kg/day	290,400 lbs/day
ADT@AFI	6.18 hrs	6.18 hrs
ADT@TFL	4.19 hrs	4.19 hrs
RFP	0.475	0.475
RSU	1,650/day	435,000/day
Aeration Tank Loadings		
BODi/AV	622 kg/1000 AVM	38.76 lbs/1000 AVF
BODi/ASU	12.4 kg/ASU	104 lbs/1000 ASU
BODi/MLVSS	0.207 g/g	0.207 lbs/lb
Purification Pressures		
ATCxADT@AFI	30.90	30.90
ATCxADT@TFL	20.95	20.95
ATCxADT@TFL/mg/l BODd	0.187	0.187
RSU/AFI	71.3 RSU/1000 cu m	71.3 RSU/1000 gals
RSU/BODi	0.446 RSU/kg BODi	53.4 RSU/lb BODi
RSTSS/BODi	35.66 kg/kg	35.66 lb/lb

FINAL CLARIFIER CHARACTERISTICS

This section includes calculation procedures for the following final clarifier characteristics that define process equilibrium, permit clarifier and process performance evaluation and dictate control adjustment requirements.

Final Clarifier Sludge Units - CSU
Final Clarifier Detention Time - CDT
Clarifier Sludge Detention Time - CSDT
Clarifier Surface Overflow Rate - OFR

The clarifier sludge detention time (CSDT) should be calculated after every control test for use along with the CSFD (clarifier sludge flow demand - described later) to determine the required clarifier sludge flow control adjustment. The number of sludge units in the final clarifier (CSU) is usually calculated from the 24-hour average of test records to determine the aerator to clarifier solids distribution ratio (SDR = ASU/CSU) and for use in sludge age calculations. The other values, CDT and OFR are used to document hydraulic and sludge loadings.

Final clarifier characteristics, flows and sludge concentrations used are illustrated in Figure 7.

FINAL CLARIFIER SLUDGE UNITS - CSU

$$\boxed{CSU = BLV \times CSC/100}$$

The sludge blanket volume (BLV) is readily calculated from the depth of blanket (DOB) readings described in Part II, CONTROL TESTS. For calculating the mean concentration of the clarifier sludge (CSC), it is implicitly assumed that sludge concentration will increase uniformly from a value approximating ATC at the upper surface of the accumulated sludge blanket to RSC at the bottom of the blanket. The mean clarifier sludge concentration (CSC) will then approximate the average of ATC and RSC.

The clarifier characteristics for the following CSU calculation examples are shown in Figure 8.

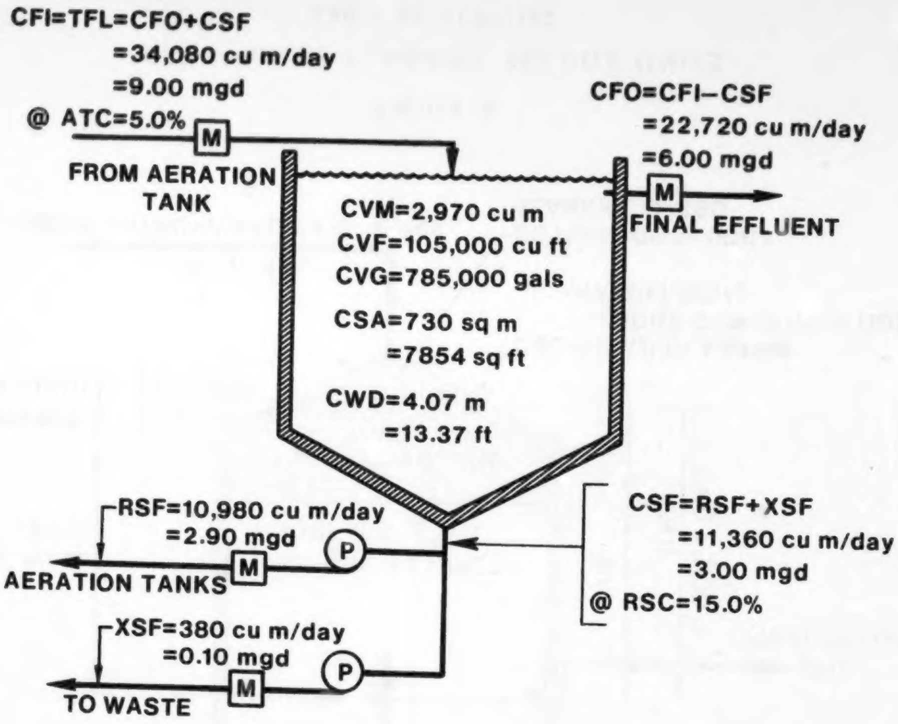

CFI=TFL=CFO+CSF
=34,080 cu m/day
=9.00 mgd
@ ATC=5.0%
M
FROM AERATION TANK
CFO=CFI−CSF
=22,720 cu m/day
=6.00 mgd
M
FINAL EFFLUENT
CVM=2,970 cu m
CVF=105,000 cu ft
CVG=785,000 gals
CSA=730 sq m
=7854 sq ft
CWD=4.07 m
=13.37 ft
RSF=10,980 cu m/day
=2.90 mgd
P
M
TO AERATION TANKS
XSF=380 cu m/day
=0.10 mgd
P
M
TO WASTE
CSF=RSF+XSF
=11,360 cu m/day
=3.00 mgd
@ RSC=15.0%

Figure 7

FINAL CLARIFIER
Volumes, Flows, and Concentrations
Used in the Examples

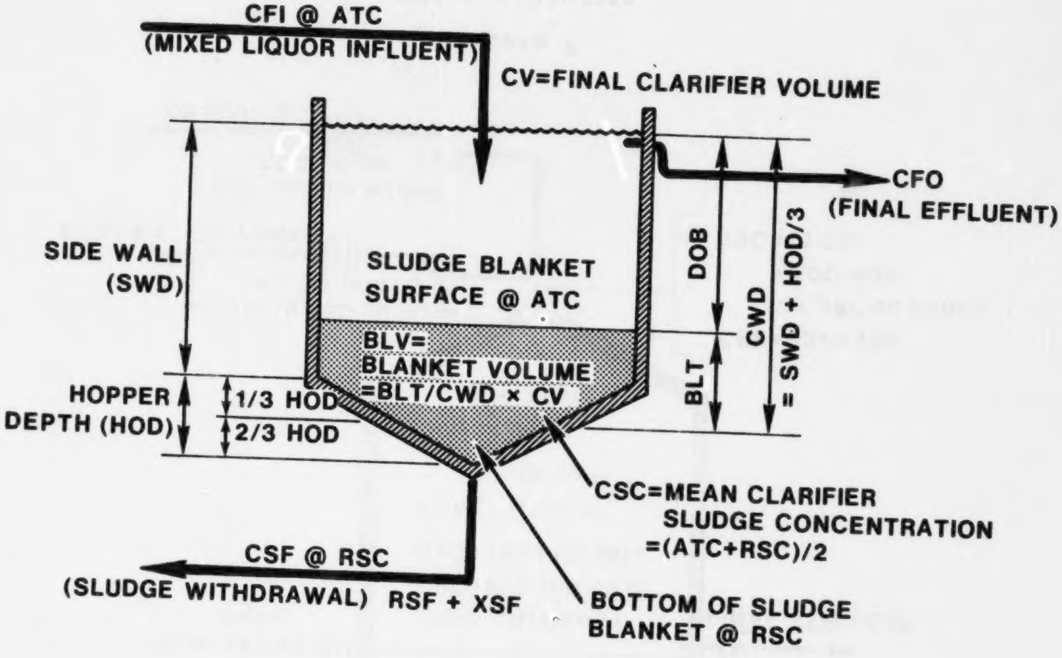

CFI @ ATC
(MIXED LIQUOR INFLUENT)
CV=FINAL CLARIFIER VOLUME
CFO
(FINAL EFFLUENT)
SIDE WALL
(SWD)
SLUDGE BLANKET
SURFACE @ ATC
BLV=
BLANKET VOLUME
=BLT/CWD × CV
DOB
BLT
CWD
= SWD + HOD/3
HOPPER
DEPTH (HOD)
1/3 HOD
2/3 HOD
CSC=MEAN CLARIFIER
SLUDGE CONCENTRATION
=(ATC+RSC)/2
CSF @ RSC
(SLUDGE WITHDRAWAL) RSF + XSF
BOTTOM OF SLUDGE
BLANKET @ RSC

Figure 8

CSU = FINAL CLARIFIER SLUDGE UNITS

CSU = BLV×CSC/100

SYMBOLS

ATC = Aeration Tank Concentration (%)
BLT = Sludge Blanket Thickness (CWD - DOB)
BLV = Sludge Blanket Volume
CSA = Final Clarifier Surface Area
CSC = Mean Clarifier Sludge Blanket Concentration = (ATC+RSC)/2
CSU = Final Clarifier Sludge Units
CV = Final Clarifier Volume
CVF = Final Clarifier Volume in Cubic Feet
CVG = Final Clarifier Volume in Gallons
CVM = Final Clarifier Volume in Cubic Meters
CWD = Final Clarifier Mean Water Depth
DOB = Depth of Sludge Blanket (Measured from water surface to upper surface of the sludge blanket)
RSC = Return Sludge Concentration (%)
SWD = Clarifier Side Water Depth

EXAMPLES

Metric Units	English Units
Observed:	**Observed:**
CVM = 2,970 cu m	CVG = 785,000 gals
CWD = 4.07 m	CWD = 13.37 ft
DOB = 2.71 m	DOB = 8.9 ft
ATC = 5.0%	ATC = 5.0%
RSC = 15.0%	RSC = 15.0%
Wanted: CSU	
Therefore:	**Therefore:**
BLT = CWD-DOB	BLT = CWD-DOB
= 4.07 - 2.71	= 13.37 - 8.9
= 1.36 m	= 4.47 ft
BLV = (BLT/CWD)xCVM	BLV = (BLT/CWD)xCVG
= (1.36/4.075)x2970	= (4.47/13.37)x785,000
= 990 cu m	= 262,400 gals
CSC = (ATC+RSC)/2	CSC = (ATC+RSC)/2
= (5.0+15.0)/2	= (5.0+15.0)/2
= 10.0%	= 10.0%

CSU = BLVxCSC/100
= 990x10.0/100
= 99 SLU

CSU = BLVxCSC/100
= 262,400x10.0/100
= 26,240 SLU

DISCUSSION

The mean sludge blanket concentration is calculated from the implicitly assumed upper surface (ATC) and bottom level (RSC) concentrations to eliminate the otherwise time consuming and impractical task of collecting and centrifuging many additional sludge samples at one- or two-foot depth intervals from each clarifier during each testing period.

These assumptions are quite realistic for full-load, optimum sludge quality and process balance. The actual upper and lower level concentrations may not, however, equal ATC and RSC when sludge settling and sewage flow rates diverge widely from optimum. Though the value calculated from each control test will not always be accurate, *the trend (increasing or decreasing) of the calculated sludge unit values will realistically represent the changes that are occurring.*

Since process evaluation and control policy are based on the study of established trends, rather than upon observation of single test results, this simplified calculation procedure is valid as well as convenient.

FINAL CLARIFIER DETENTION TIME - CDT

$$\boxed{CDT = (CVx24)/CFI}$$

SYMBOLS

CDT = Final Clarifier Detention Time based on CFI (hrs)
CFI = Final Clarifier Flow-In
CV = Final Clarifier Volume
CVG = Final Clarifier Volume in gals
CVM = Final Clarifier Volume in cu m

EXAMPLES

Metric Units	English Units
Observed:	Observed:
CVM = 2,970 cu m CFI = 34,080 cu m/d	CVG = 0.7850 million gal CFI = 9.000 MGD
Wanted: CDT	
Therefore:	Therefore:
CDT = (CVMx24)/CFI = (2.970x24)/34,080 = 2.09 hrs	CDT = (CVGx24)/CFI = (0.7850x24)/9.0 = 2.09 hrs

CLARIFIER SLUDGE DETENTION TIME - CSDT

$$\boxed{CSDT = CSU/CSUO}$$

The sludge detention time in the final clarifier is determined by dividing the number of sludge units accumulated in the clarifier by the rate at which sludge units are removed from the clarifier. See Figure 9.

SYMBOLS

CSDT = Final Clarifier Sludge Detention Time (hrs)
CSF = Final Clarifier Sludge Flow
CSU = Final Clarifier Sludge Units
CSUO = Final Clarifier Sludge Units-Out
RSC = Return Sludge Concentration (%)
RSF = Return Sludge Flow
XSF = Excess Sludge Flow to waste

EXAMPLES

Metric Units	English Units
Observed:	Observed:
CSU = 99 RSC = 15.0% RSF = 10,980 cu m/day XSF = 380 cu m/day	CSU = 26,240 RSC = 15.0% RSF = 2.900 mgd XSF = 0.100 mgd

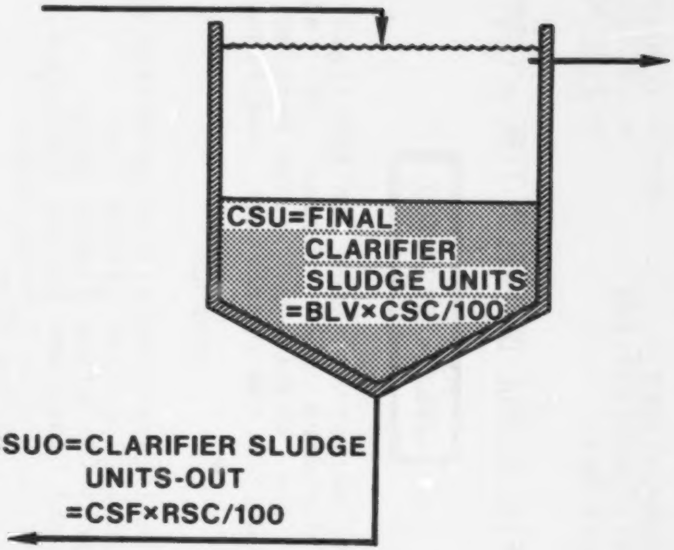

CSU=FINAL
CLARIFIER
SLUDGE UNITS
=BLV×CSC/100
CSUO=CLARIFIER SLUDGE
UNITS-OUT
=CSF×RSC/100

Figure 9

CSDT = CLARIFIER SLUDGE DETENTION TIME

CSDT = CSU/CSUO

Wanted: CSDT

Therefore:

CSF = RSF+XSF
= 10,980+380
= 11,360 cu m/day

CSUO = CSFxRSC/100
= (11,360x15.0)/100
= 1700 SLU/day
= 1700/24 = 71 SLU/hr

CSDT = CSU/CSUO
= 99/71 = 1.39 hrs

Therefore:

CSF = RSF+XSF
= 2.9+0.1
= 3.000 mgd

CSUO = CSFxRSC/100
= 3,000,000x15.0/100
= 450,000 SLU/day
= 450,000/24 = 18,750 SLU/hr

CSDT = CSU/CSUO
= 26,240/18,750 = 1.40 hrs

FINAL CLARIFIER SURFACE OVERFLOW RATE - OFR

OFR = CFO/CSA

SYMBOLS

CSA = Final Clarifier Surface Area
CFO = Final Clarifier Flow-Out (Final Effluent)
OFR = Final Clarifier Surface Overflow Rate

EXAMPLES

Metric Units

Observed:

CFO = 22,720 cu m/d
CSA = 730 sq m

Wanted: OFR

Therefore:

OFR = CFO/CSA
= 22,720/730
= 31.1 cu m/day/sq m

English Units

Observed:

CFO = 6.000 mgd
CSA = 7854 sq ft

Therefore:

OFR = CFO/CSA
= 6,000,000/7,854
= 764 gals/day/sq ft

PROCESS CHARACTERISTICS

SLUDGE AERATION HOURS - SAH

SAH = (ADTx24)/(ADT+CSDT)

Activated sludge oxidation is influenced by the number of hours the sludge resides in the aeration tanks during each 24-hour cycle.

SYMBOLS

ADT - Aeration Tank Detention Time
CSDT - Final Clarifier Sludge Detention Time
SAH - Sludge Aeration Hours per day

EXAMPLES

Observed:

ADT = 4.19 hrs (@TFL)
CSDT = 1.39 hrs

Wanted: SAH

Therefore:

SAH = (ADTx24)/(ADT+CSDT)
= (4.19x24)/(4.19+1.39)
= 18.0 hrs/day

SLUDGE AGE - AGE & AAG

AGE = (ASU+CSU) / TXU/day
AAG = AGExSAH/24

The following method of calculating sludge age is used while the Waste Treatment Branch is developing an improved method. The improved method will be included in a future issue of this pamphlet series if it proves practical and more realistic.

Sludge age, being the average time that sludge solids remain in the activated sludge plant, can vary from few to many days. Using 24-hour average data for each day's sludge age calculation could obviously cause gross errors. If no sludge were wasted on one day, for example, the calculation would erroneously imply an infinite sludge age.

It is therefore suggested that the 7-day moving averages of TSU, TXU etc, be used to compute sludge age. Seven days is a reasonable time span and it includes all data for every day in a calendar week. For instance, the sludge age calculation on Thursday would be based on the averages of all appropriate data collected during the previous Friday, Saturday, Sunday, Monday, Tuesday, Wednesday and the current Thursday. This procedure also minimizes the discrepancy that can be introduced when no sludge is wasted for a day or two. In this case, the one or two zeros would be averaged in with the other TXU values for the remaining 5 or 6 days in the 7-day moving average time interval. The moving average concept is described and illustrated in the Appendix.

Obviously, with a clear final effluent ESU becomes very small. Under this condition TXU will nearly equal XSU. But, the ESU term becomes significant under "bulking" conditions, for example, as final effluent becomes degraded, i.e solids are discharged with the final clarifier overflow.

SYMBOLS

AAG - Aeration Age. Number of days the sludge was subjected to aeration.
AGE - Sludge Age in days.
ASU - Aeration Tank Sludge Units
CFO - Final Clarifier Flow-Out
CSU - Final Clarifier Sludge Units
ESU - Final Effluent Sludge Units
FEC - Final Effluent Concentration (%)
FETSS - Final Effluent Total Suspended Solids (mg/l)
SAH - Sludge Aeration Hours per day
TXU - Total Excess Sludge Units removed (XSU+ESU)
WCR - Sludge Weight-to-Concentration Ratio
XSC - Excess Sludge Concentration
XSF - Excess Sludge Flow to Waste
XSU - Excess Sludge Units Wasted

EXAMPLES

Metric Units

Observed:

ASU = 297 SLU
CSU = 99 SLU
XSF = 380 cu m/day
XSC = 15.0%
CFO = 22,720 cu m/day
FETSS = 10.0 mg/l
WCR = 800
SAH = 18 hrs/day

Wanted: AGE & AAG

Therefore:

XSU = XSFxXSC/100
= 380x15.0/100
= 57 SLU/day

FEC = FETSS/WCR
= 10/800
= 0.0125%

ESU = CFOxFEC/100
= 22,720x0.0125/100
= 2.84 SLU/day

TXU = XSU+ESU
= 57+3
= 60 SLU/day

AGE = (ASU+CSU)/TXU/day
= (297+99)/60
= 6.6 days

AAG = AGExSAH/24
= 6.6x18/24
= 5.0 days

English Units

Observed:

ASU = 78,550 SLU
CSU = 26,240 SLU
XSF = 0.100 mgd
XSC = 15.0%
CFO = 6.0 mgd
FETSS = 10.0 mg/l
WCR = 800
SAH = 18 hrs/day

Therefore:

XSU = XSFxXSC/100
= 100,000x15.0/100
= 15,000 SLU/day

FEC = FETSS/WCR
= 10/800
= 0.0125%

ESU = CFOxFEC/100
= 6,000,000x0.0125/100
= 750 SLU/day

TXU = XSU+ESU
= 15,000+750
= 15,750 SLU/day

AGE = (ASU+CSU)/TXU/day
= (78,550+26,240)/15,750
= 6.6 days

AAG = AGExSAH/24
= 6.6x18/24
= 5.0 days

SLUDGE CONCENTRATION RATIO - SCR

$$\boxed{\text{SCR} = \text{SSC60/RSC}}$$

The sludge concentration ratio reveals process balance status, and indicates control adjustment needs. It shows how closely the controlled return sludge concentration approached the desired settled sludge concentration that had been determined from the settlometer test.

The SSC settlometer test results should be plotted on a trend chart as illustrated in the Appendix. The RSC values should also be shown, as enlarged dots, on this trend chart to indicate how far they may have strayed from the desired SSC values.

The SCR, therefore, refines impressions received from the trend chart and provides numerical values that can be used to analyse process balance and to set target values for return sludge flow demand calculations.

An SCR between 1.0 and 1.2 usually indicates good balance. Values less than 0.9 or greater than 2.0 reveal the need for process adjustment.

SYMBOLS

RSC = Return Sludge Concentration (%)
SCR = Sludge Concentration Ratio
SSC60 = Settled Sludge Concentration at 60 minutes

EXAMPLES

Observed:	Case A	Case B	Case C
SSC60 =	15.0	8.0	16.5
RSC =	14.0	10.0	7.5

Wanted: SCR

Therefore:

SCR =	SSC60/RSC	SSC60/RSC	SSC60/RSC
=	15.0/14.0	8.0/10.0	16.5/7.5
=	1.07	0.80	2.2

The SCR in Case A reveals good process balance, but the SCR in Case B is too low and that in Case C is too high.

CLARIFIER SLUDGE FLOW DEMAND - CSFD

$$\boxed{\text{CSFD} = \text{CSF} \times (\text{RSC}-\text{ATC})/(\text{SSC}-\text{ATC})}$$

This CSFD Formula is used to determine the clarifier sludge removal flow rate (CSF) needed to maintain proper process balance. It should be computed at the end of each testing period, after which the operator should adjust the CSF to equal the CSFD.

The operator should also compute the CSDT, as shown in the final clarifier section, to determine whether the final clarifier sludge residence time approximates 1.0 hour, or is at least within the tolerable limits of from 0.75 to 1.5 hours.

The use of these formulas for process evaluation and control is discussed in Part IV PROCESS CONTROL.

SYMBOLS

ATC = Aeration Tank Concentration (%)
CSF = Final Clarifier Sludge Flow
CSFD = Clarifier Sludge Flow Demand
RSC = Return Sludge Concentration (%)
SSC = Settled Sludge Concentration (%)

EXAMPLES

Metric Units	English Units
Observed:	Observed:
CFO = 22,720 cu m/day	CFO = 6.000 mgd
CSF = 11,360 cu m/day	CSF = 3.000 mgd
ATC = 5.0%	ATC = 5.0%
RSC = 15.0%	RSC = 15.0%
SSC = 13.0%	SSC = 13.0%

Wanted: CSFD needed to reduce RSC from 15.0 to 13.0

Therefore:

CSFD = CSFx(RSC-ATC)
/(SSC-ATC)

= 11,360 (15.0-5.0)
/(13.0-5.0)

= 11,360x10.0/8.0

= 14,200 cu m/day

Therefore:

CSFD = CSFx(RSC-ATC)
/(SSC-ATC)

= 3.0(15.0-5.0)
/(13.0-5.0)

= 3.0x10.0/8.0

= 3.75 mgd

MIXING FORMULA DEVELOPMENT

SYMBOLS FOR MIXING FORMULAS

AFI = Aeration Tank Waste Water Flow-In
ATC = Aeration Tank Concentration (%)
CFI = Final Clarifier Flow-In
CFO = Final Clarifier Flow-Out (Final Effluent)
CFP = Final Clarifier Sludge Flow Percentage (expressed decimally)
CSF = Clarifier Sludge Flow (Usually = RSF+XSF)
FEC = Final Effluent Solids Conc. (%)
FETSS = Final Effluent Total Suspended Solids (mg/l)
MLTSS = Mixed Liquor Total Suspended Solids (mg/l)
PEC = Primary Effluent Solids Conc. (%)
PETSS = Primary Effluent Total Suspended Solids (mg/l)
RSC = Return Sludge Concentration (%)
RSF = Return Sludge Flow
RSP = Return Sludge Flow Percentage based on a mass balance around the inlet end of the aeration tank (expressed decimally)
SLU = Sludge Units
CSUI = Final Clarifier Sludge Units-In
CSUO = Final Clarifier Sludge Units-Out
WCR = Sludge Weight-to-Concentration Ratio
XSF = Excess Sludge Flow to Waste

SIMPLIFIED MIXING FORMULAS

(See Figure 10)

A. Define the Flow Equality.

The sum of the final effluent and clarifier sludge flow out of the final clarifier must equal the mixed liquor flow into the clarifier.

Flow Out = Flow In
CFO + CSF = CFI (1)

Express CSF and CFI as functions of CFO and CFP.

CSF = CFO x CFP (2)
CFI = CFO (1.0+CFP) (3)

Now substitute the right hand terms of equations (2) and (3) for CSF and CFI in equation (1)

$$\text{Flow Out} = \text{Flow In}$$
$$CFO+(CFO\times CFP) = CFO(1.0+CFP) \qquad (4)$$

B. Define the Sludge Unit Equality

The number of sludge units flowing out of the final clarifier will be the sum of FEC/100 multiplied by the final effluent flow plus RSC/100 multiplied by the clarifier sludge flow. The number of sludge units entering the clarifier will be ATC/100 multiplied by the mixed liquor flow.

By multiplying the terms in equation (4) by the appropriate concentrations, the sludge unit equality becomes:

$$\begin{aligned} & CFO \times FEC/100 + (CFO \times CFP) \times RSC/100 \\ & = CFO\ (1.0 + CFP) \times ATC/100 \qquad (5) \end{aligned}$$

The final effluent suspended solids concentration is exceedingly low compared to the mixed liquor and return sludge concentrations in an activated sludge plant that is performing properly. Under such conditions, the number of sludge units carried out in the final effluent can be neglected and equation (5) can be simplified to:

$$CFO \times CFP \times RSC/100 = CFO\ (1.0 + CFP) \times ATC/100 \qquad (6)$$

After cancelling the common CFO and 100 terms from both sides of equation (6) it can be further simplified to include only ATC, RSC and CFP as follows:

$$\begin{aligned} & CFP \times RSC = (1.0 + CFP) \times ATC \\ & CFP \times RSC = ATC + (CFP \times ATC) \\ & (CFP \times RSC) - (CFP \times ATC) = ATC \\ & CFP\ (RSC - ATC) = ATC \\ & CFP = ATC\ /\ (RSC - ATC) \qquad (7) \end{aligned}$$

The CFP equation (7) can now be transformed to the other two mixing formulas so that any single unknown can be calculated from the other two known or measured values.

$$\boxed{\begin{aligned} CFP &= ATC/(RSC-ATC) \\ ATC &= CFP\times RSC/(CFP+1.0) \\ RSC &= ATC+(ATC/CFP) \end{aligned}}$$

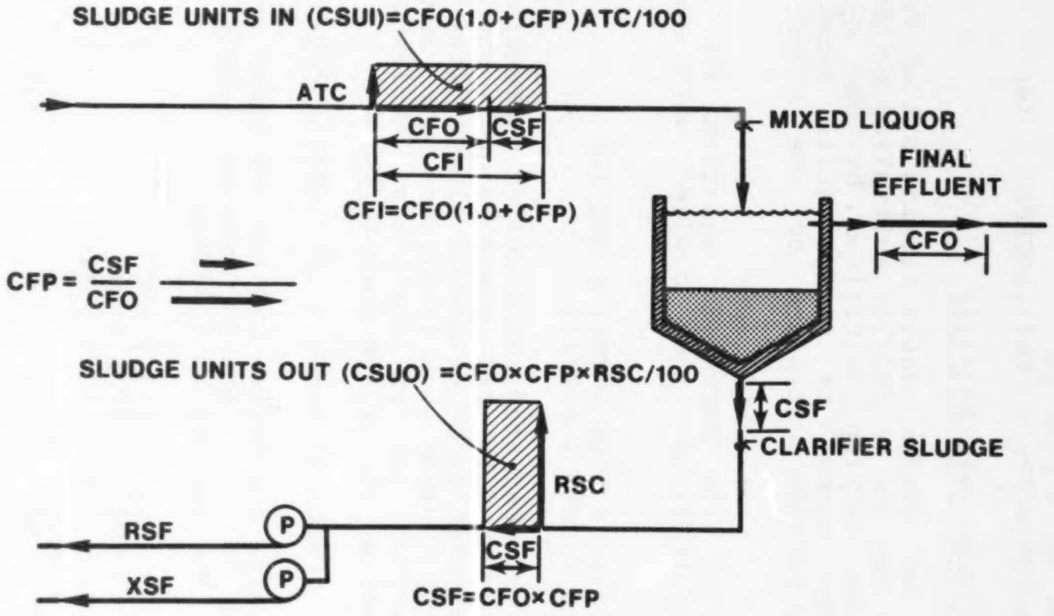

SLUDGE UNITS IN (CSUI)=CFO(1.0+CFP)ATC/100
ATC
CFO
CSF
CFI
CFI=CFO(1.0+CFP)
MIXED LIQUOR
FINAL EFFLUENT
CFO
CFP = CSF/CFO
SLUDGE UNITS OUT (CSUO) =CFO×CFP×RSC/100
CSF
CLARIFIER SLUDGE
RSC
RSF
XSF
P
P
CSF
CSF=CFO×CFP

Figure 10

MASS BALANCE FOR
MIXING FORMULA DEVELOPMENT

$$CSUI = CSUO$$

$$CFO(1.0+CFP)ATC = CFO \times CFP \times RSC$$

EXPANDED MIXING FORMULAS

TO INCLUDE SIGNIFICANT PRIMARY EFFLUENT (PEC) OR FINAL EFFLUENT (FEC) SUSPENDED SOLIDS CONCENTRATIONS.

In high rate activated sludge plants for example, where the primary effluent suspended solids concentration may be significant compared to very low mixed liquor suspended solids concentrations, it is usually necessary to use mixing formulas that have been expanded to account for primary effluent solids.

Recognition and use of final effluent solids concentrations in expanded mixing formulas may also be necessary whenever significant amounts of sludge solids are washed out of the process final effluent during sludge "bulking".

In either case, a preliminary calculation is usually necessary to convert the primary effluent or final effluent suspended solids concentrations to equivalent centrifuge values (PEC and FEC) before using the expanded formulas. Since the sludge weight to centrifuged sludge concentration ratio (WCR) is usually determined daily, these approximate centrifuge concentration equivalents (PEC and FEC) can be computed as follows:

Primary Effluent	Final Effluent
PEC = PETSS/WCR	FEC = FETSS/WCR
Observed:	Observed:
PETSS = 240 mg/l WCR = 800	FETSS = 480 mg/l WCR = 800
Wanted: PEC	Wanted: FEC
Therefore:	Therefore:
PEC = PETSS/WCR = 240/800 = 0.30%	FEC = FETSS/WCR = 480/800 = 0.60%

The expanded formulas can then be derived according to the same mass balance techniques that were described for the Simplified Mixing Formula development.

CFO and FEC must, however, be included in the derivation to account for sludge units in the final effluent.

AFI and PEC must be included in the derivation of the formulas that are expanded to include primary effluent solids. Since these formulas are based on a mass balance of solids entering and leaving the aeration tanks, AFI, RSF and RSP are used instead of the CFO, CSF and CFP values that were used in the mass balance around the final clarifier.

Such derivations will then provide the following two sets of mixing formulas to include significant final effluent or primary effluent suspended solids concentrations:

FOR SIGNIFICANT FINAL EFFLUENT SOLIDS

CFP = (ATC-FEC)/(RSC-ATC)
ATC = (CFPxRSC)+FEC/(CFP+1.0)
RSC = ATC+ (ATC-FEC)/CFP

FOR SIGNIFICANT PRIMARY EFFLUENT SOLIDS

RSP = (ATC-PEC)/(RSC-ATC)
ATC = (RSPxRSC)+PEC/(RSP+1.0)
RSC = ATC+ (ATC-PEC)/RSP

CLARIFIER SLUDGE FLOW DEMAND FORMULA DEVELOPMENT

SYMBOLS FOR THE CLARIFIER SLUDGE FLOW DEMAND FORMULA

ATC = Aeration Tank Concentration (%)
CFO = Final Clarifier Flow-Out (Final Effluent)
CSF = Final Clarifier Sludge Flow
CFP = Final Clarifier Sludge Flow Percentage (expressed decimally)
CSUI = Final Clarifier Sludge Units-In (Mixed Liquor)
CSUO = Final Clarifier Sludge Units-Out (Return plus waste sludge)
CSFD = Clarifier Sludge Flow Demand
RSC = Return Sludge Concentration (%)
SSC = Settled Sludge Concentration (%)

DEVELOPMENT OF THE CLARIFIER SLUDGE FLOW DEMAND FORMULA

(SEE FIGURE 11)

The CSFD formula is developed by expressing the clarifier sludge flow as a percent of the sewage flow.

$$\mathrm{CSF} = \mathrm{CFO}\times\mathrm{CFP} \tag{1}$$

CFP is then expressed in terms of RSC and ATC according to the mixing formulas.

$$\mathrm{CFP} = \mathrm{ATC}/(\mathrm{RSC}-\mathrm{ATC}) \tag{2}$$

The solids concentration relationship in equation (2) is now substituted for CFP in equation (1) and:

$$\mathrm{CSF} = \mathrm{CFO}\times\mathrm{ATC}/(\mathrm{RSC}-\mathrm{ATC}) \tag{3}$$

By transposing the terms in equation (3) it becomes:

$$\mathrm{CFO}\times\mathrm{ATC} = \mathrm{CSF}\times(\mathrm{RSC}-\mathrm{ATC}) \tag{4}$$

Substituting the desired clarifier sludge concentration (SSC) and the unknown clarifier sludge flow demand (CSFD), for RSC and CSF respectively in equations (1), (2), and (3) will give:

$$CFOxATC = CSFD(SSC-ATC) \qquad (5)$$

Since the right hand terms in equations (4) and (5) are each equal to (CFOxATC), they are equal to each other, and:

$$CSFD(SSC-ATC) = CSF(RSC-ATC)$$

$$\boxed{CSFD = CSF(RSC-ATC)/(SSC-ATC)}$$

DISCUSSION AND CHECK ON THE FORMULA

The number of sludge units in the mixed liquor entering the final clarifier must equal, or approximate in actual practice, the number of sludge units in the clarifier sludge pumped out from the bottom of the clarifier.

Though the return sludge concentration (RSC) will change rapidly in response to a clarifier sludge flow (CSF) adjustment, the mixed liquor concentration (ATC) entering the clarifier will change only slightly, if at all, when the process balance is near optimum equilibrium.

Following is a mass balance check on the results from the CSFD example in the Process Characteristics Section.

CSUI must equal CSUO

Observed:

CSUI = (6.0+3.0)x5.0/100 = 0.450 million SLU/day
CSUO = 3.0x15.0/100 = 0.450 million SLU/day

The observed sludge units entering the final clarifier equal those leaving the clarifier.

Demand:

CSUI = (6.0+3.75)x5.0/100 = 0.4875 million SLU/day
CSUO = 3.75x13.0/100 = 0.4875 million SLU/day

Sludge units entering the final clarifier will equal those leaving the clarifier after the clarifier sludge is increased from 3.0 mgd to meet the 3.75 mgd clarifier sludge flow demand.

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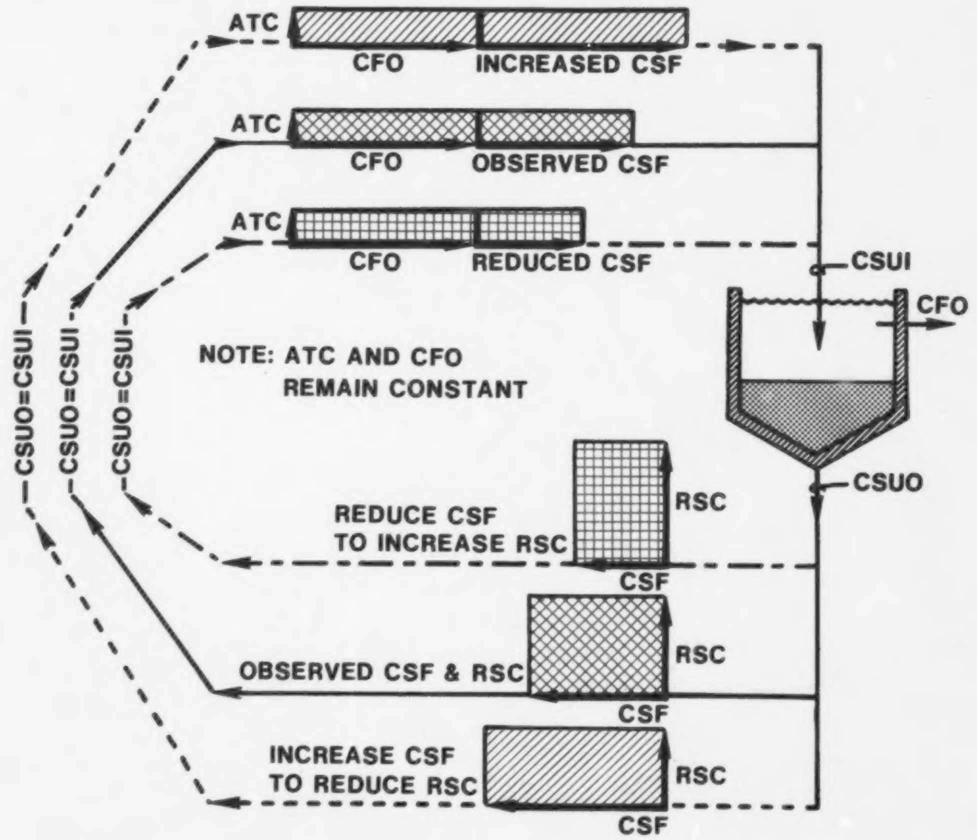
ATC
CFO
INCREASED CSF
ATC
CFO
OBSERVED CSF
ATC
CFO
REDUCED CSF
CSUI
CFO
CSUO
NOTE: ATC AND CFO REMAIN CONSTANT
CSUO=CSUI
CSUO=CSUI
CSUO=CSUI
REDUCE CSF TO INCREASE RSC
RSC
CSF
OBSERVED CSF & RSC
RSC
CSF
INCREASE CSF TO REDUCE RSC
RSC
CSF

Figure 11

MASS BALANCE FOR CSFD

CFD = CSF(RSC−ATC)/(SSC−ATC)

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SUMMARY OF

FORMULAS AND CALCULATED RESULTS

PARAMETERS	FORMULAS OR PROCEDURE	VALUES SHOWN IN EXAMPLE CALCULATIONS METRIC UNITS	ENGLISH UNITS	EXAMPLE REFERENCE ON PAGE
HYDRAULIC LOADINGS				
ADT @ AFI	(AV x 24) / AFI	6.18 HRS	6.18 HRS	24
ADT @ TFL	(AV x 24) / (AFI + RSF)	4.19 HRS	4.19 HRS	24
CDT	(CV x 24) / CFI	2.09 HRS	2.09 HRS	33
OFR	CFO / CSA	31.1 CU M/DAY/SQ M	764 GPD/SQ FT	35
BOD LOADINGS				
BODi / AV	WT OF BODi / 1000 AV	622 KG/1000 AVM	38.76 LBS/1000 AVF	27
BODi / ASU	WT OF BODi / ASU	12.4 KG/ASU	104 LBS/1000 ASU	27
BODi / MLVSS	WT OF BODi / WT OF MLVSS	0.207 KG/KG	0.207 LBS/LB	27
PURIFICATION PRESSURES				
ATC x ADT @ AFI	DIRECT CALCULATION	30.90	30.90	27
ATC x ADT @ TFL	DIRECT CALCULATION	20.95	20.95	27
ATC x ADT / MG/L BODi	DIRECT CALCULATION	0.187	0.187	27
RSU / AFI	DIRECT CALCULATION	71.3 RSU/1000 CU M	71.3 RSU/1000 GAL	27
RSU / AFI BODi	DIRECT CALCULATION	0.446 RSU/KG BODi	53.4 RSU/LB BODi	27
RSTSS / BODi	WT OF RSTSS / WT OF BODi	35.66 KG/KG	35.66 LB/LB	27
SLUDGE QUALITY				
SSV 5	SETTLOMETER READING	630 CC/L	630 CC/L	10
SSV60	SETTLOMETER READING	200 CC/L	200 CC/L	10
* ATC	CENTRIFUGE READING	3 %	3 %	10
SSC60	1000 x ATC / SSV60	15 %	15 %	10
SCR	SSC60 / RSC	0.8 to 2.2	0.8 to 2.2	39
WCR	MLTSS / ATC	500 TO 1,000	500 TO 1,000	5
SIMPLE MIXING FORMULAS				
CFP	ATC / (RSC - ATC)	0.50	0.50	13
ATC	(CFP x RSC) / (CFP + 1.0)	5 %	5 %	17
RSC	ATC + (ATC / CFP)	15.0 %	15.0 %	18
PROCESS RELATIONSHIPS				
DOB	MEASURED	2.71 M	8.9 FT	31
BLT	CWD - DOB	1.36 M	4.47 FT	31
BLV	(BLT / CWD) x CV	990 CU M	262,400 GALS	31
CSC	(ATC + RSC) / 2	10 %	10 %	31
ASU	AV x ATC / 100	297 SLU	78,550 SLU	22
CSU	BLV x CSC / 100	99 SLU	26,240 SLU	32
TSU	ASU + CSU	396 SLU	104,790 SLU	-
RSU	RSF x RSC / 100	1,650 SLU/DAY	435,000 SLU/DAY	23
SDR	ASU / CSU	3.0	3.0	28
CSF	RSF + XSF	11,360 CU M/DAY	3.0 MGD	35
CSUI / DAY	CFI x ATC / 100	1,700 SLU/DAY	450,000 SLU/DAY	48
CSUO / DAY	CSF x RSC / 100	1,700 SLU/DAY	450,000 SLU/DAY	35
CSUO / HOUR	CSUO/DAY / 24	71 SLU/HR	18,750 SLU/HR	35
CSDT	CSU / CSUO/HOUR	1.39 HRS	1.40 HRS	35
CFP	100 x CSF / CFO	50.0 %	50.0 %	15
CFP	100 x ATC / (RSC - ATC)	50.0 %	50.0 %	13
RFP	100 x RSF / AFI	47.5 %	47.5 %	15
SAH	(ADT x 24) / (ADT + CSDT)	18 HRS/DAY	18 HRS/DAY	36
XSU	XSF x XSC / 100	57 SLU/DAY	15,000 SLU/DAY	38
FEC	FETSS / WCR	0.0125 %	0.0125 %	38
ESU	CFO x FEC / 100	2.84 SLU/DAY	750 SLU/DAY	38
TXU	XSU + ESU	60 SLU/DAY	15,750 SLU/DAY	38
AGE	TSU / TXU/DAY	6.6 DAYS	6.6 DAYS	38
AAG	AGE x SAH / 24	5 DAYS	5 DAYS	38
CLARIFIER SLUDGE FLOW DEMAND				
CSFD	CSF x (RSC - ATC) / (SSC - ATC)	14,200 CU M/DAY	3.75 MGD	40

* ATC OF 3.0 USED IN THE SSC EXAMPLE.

EQUIVALENTS USED FOR ACTIVATED SLUDGE CALCULATIONS

ft x 0.3048 = m
inches x 2.540 = cm
m x 3.28083 = ft
m x 39.37 = in

sq ft x 0.0929 = sq m
sq m x 10.7639 = sq ft

cu ft x 28.3170 = liter
cu ft x 0.028317 = cu m
cu ft x 7.48052 = gal
cu m x 1000.0 = liter
cu m x 35.3145 = cu ft
cu m x 264.179 = gal

gal x 3.785 = liter
gal x 0.003785 = cu m
liter x 0.26417 = gal
mgd x 3785 = cu m/day
cu m/day x 0.000264 = mgd

gpd/sq ft x 0.0408 = cu m/day/sq m
cu m/day/sq m x 24.51 = gpd/sq ft

lb x 0.453592 = kg
lb x 453.592 = g
kg x 2.20462 = lb
kg x 1000.0 = g

lbs/1000 cu ft x 16.0 = g/cu m
g/cu m x 0.0625 = lbs/1000 cu ft

cu ft (H_2O) x 62.4 = lb (H_2O)
gal (H_2O) x 8.345 = lb (H_2O)
liter (H_2O) x 1.000 = kg (H_2O)

lb/day = mgd x mg/l x 8.345
kg/day = cu m/day x mg/l /1000

lb = English SLU x (WCR*/1198)
kg = Metric SLU x (WCR/10)

English SLU = Metric SLU x 264.2
Metric SLU = English SLU x 0.003785

*WCR = sludge weight (mg/l)/centrifuged concentration (%)

EPA-330/9-74-001d

NATIONAL WASTE TREATMENT CENTER - CINCINNATI

OPERATIONAL CONTROL PROCEDURES
FOR THE
ACTIVATED SLUDGE PROCESS

APPENDIX

by

Alfred W. West, P.E.

Director, National Waste Treatment Center
(formerly Waste Treatment Branch, National Field
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MARCH 1974
(Revised Nov.,1975)

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF WATER PROGRAM OPERATIONS

FOREWORD

The National Waste Treatment Center (Cincinnati) is developing a series of pamphlets describing Operational Control Procedures for the Activated Sludge Process. This series, describing the "NWTC Procedures", will include Part I OBSERVATIONS, Part II CONTROL TESTS, Part III CALCULATION PROCEDURES, Part IV SLUDGE QUALITY, Part V PROCESS CONTROL and an APPENDIX. Each of these individual parts will be released for distribution as soon as it is completed, though not necessarily in numerical order. The original five-part series may then be expanded to include case histories and refined process evaluation and control techniques.

This pamphlet has been developed as a reference for Activated Sludge Plant Control lectures I have presented at training sessions, symposia, and workshops. It is based on my personal conclusions reached while directing the operation of dozens of different activated sludge plants. This pamphlet is not necessarily an expression of Environmental Protection Agency policy or requirements.

The mention of trade names or commercial products in this pamphlet is for illustrative purposes and does not constitute endorsement or recommendation for use by the Environmental Protection Agency.

Alfred W. West

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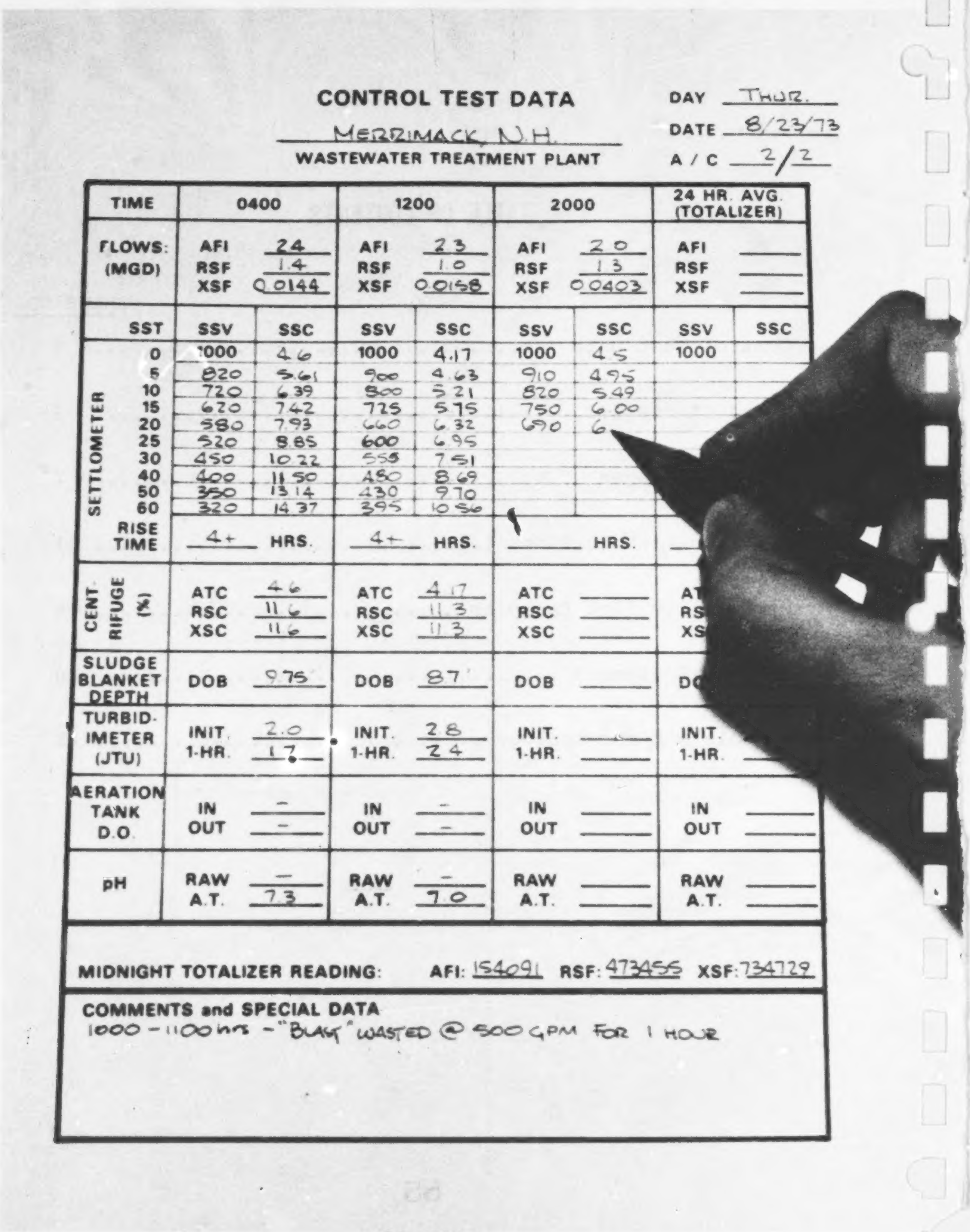


CONTROL TEST DATA

MERRIMACK, N.H.
WASTEWATER TREATMENT PLANT

DAY THUR.
DATE 8/23/73
A / C 2/2

TIME	0400		1200		2000		24 HR. AVG. (TOTALIZER)	
FLOWS: (MGD)	AFI 24 RSF 1.4 XSF 0.0144		AFI 23 RSF 1.0 XSF 0.0158		AFI 20 RSF 13 XSF 0.0403		AFI RSF XSF	
SST	SSV	SSC	SSV	SSC	SSV	SSC	SSV	SSC
SETTLOMETER 0	1000	4.6	1000	4.17	1000	4.5	1000	
5	820	5.61	900	4.63	910	4.95		
10	720	6.39	800	5.21	820	5.49		
15	620	7.42	725	5.75	750	6.00		
20	580	7.93	660	6.32	690	6		
25	520	8.85	600	6.95				
30	450	10.22	555	7.51				
40	400	11.50	480	8.69				
50	350	13.14	430	9.70				
60	320	14.37	395	10.56				
RISE TIME	4+ HRS.		4+ HRS.		HRS.			
CENTRIFUGE (%)	ATC 4.6 RSC 11.6 XSC 11.6		ATC 4.17 RSC 11.3 XSC 11.3		ATC RSC XSC		AT RS XS	
SLUDGE BLANKET DEPTH	DOB 9.75		DOB 8.7'		DOB		DO	
TURBIDIMETER (JTU)	INIT. 2.0 1-HR. 1.7		INIT. 2.8 1-HR. 2.4		INIT. 1-HR.		INIT. 1-HR.	
AERATION TANK D.O.	IN – OUT –		IN – OUT –		IN OUT		IN OUT	
pH	RAW – A.T. 7.3		RAW – A.T. 7.0		RAW A.T.		RAW A.T.	

MIDNIGHT TOTALIZER READING: AFI: 154091 RSF: 473455 XSF: 734729

COMMENTS and SPECIAL DATA
1000 - 1100 hrs - "BLAK" WASTED @ 500 GPM FOR 1 HOUR

CONTROL TEST DATA

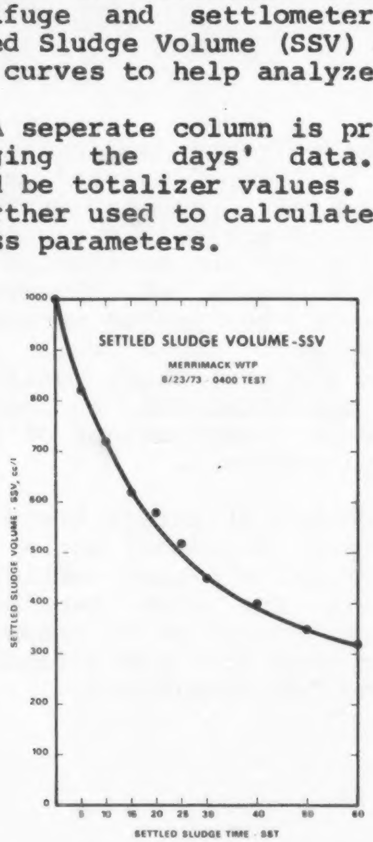
Data from the control tests described in Part II Control Tests should be recorded in an organized manner at each test period. A generalized data sheet suitable for this purpose is shown on the facing page.

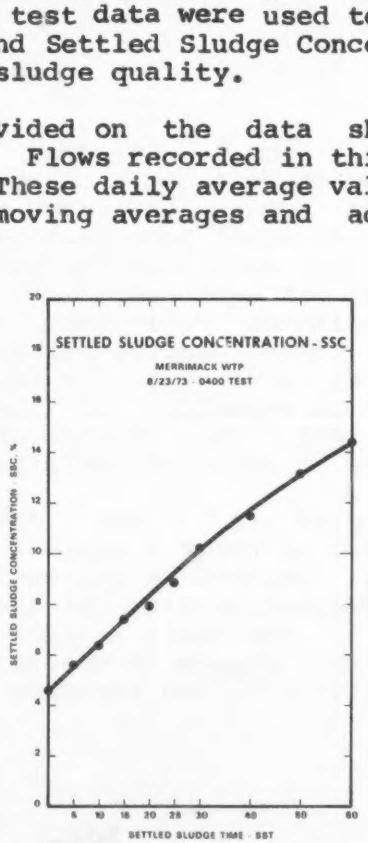
The test times shown near the top of the sheet will not be standard for each plant but will normally be determined by personnel shift changes and diurnal flow or load variation. At times additional centrifuge and depth of blanket tests may be desireable. These data may be recorded at the bottom of the sheet under comments and special data.

Except for the Settled Sludge Concentration (SSC) values, all numbers recorded on the data sheet are observed values. The SSC's are calculated as described in Part IIIA - Calculation Procedures.

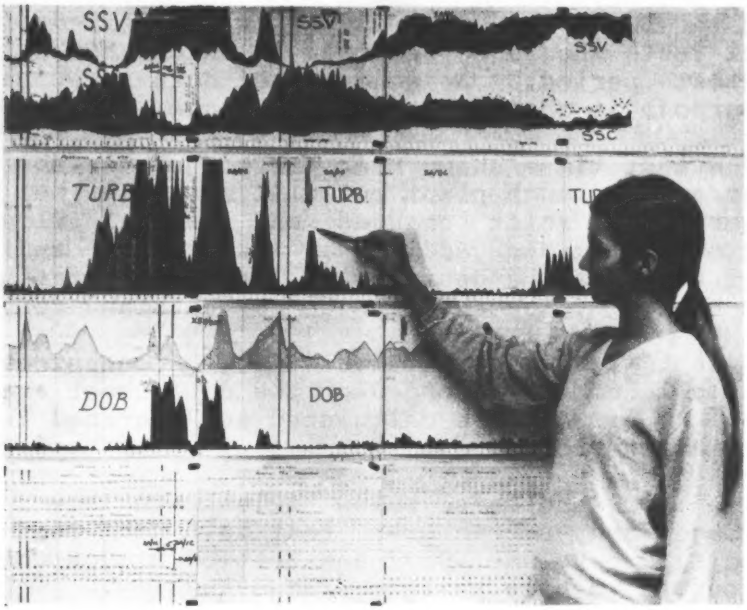
The two sketches below illustrate how the 0400 centrifuge and settlometer test data were used to develop Settled Sludge Volume (SSV) and Settled Sludge Concentration (SSC) curves to help analyze sludge quality.

A seperate column is provided on the data sheet for averaging the days' data. Flows recorded in this column should be totalizer values. These daily average values will be further used to calculate moving averages and additional process parameters.





TREND CHARTS



Data from individual daily tests and calculations should be graphically displayed on "Trend Charts" so that operators coming on duty can tell process status at a glance. At least once each day, and preferably during each shift, the data from the settlometer and centrifuge tests, the final effluent turbidity, the depth of blanket, and other selected parameters should be posted on the Trend Charts. These charts, usually kept on a wall in the laboratory area where the tests are performed, contain much of the data essential to the operation of an activated sludge plant. They provide graphic illustrations of process responses to selected operational controls.

Figures 1, 2 and 3 are copies of actual trend charts maintained by Waste Treatment Branch personnel at a recent technical assistance project. Final effluent turbidity and other selected process parameters are also tabulated on Figure 3. The heavy line through August 20 on these charts delineates a change in operating mode from two aerators and one clarifier to two aerators and two clarifiers.

The symbols, control tests and calculation procedures for determining the parameters illustrated on Figures 1, 2 and 3 have been explained in previous Parts of this series. For convenient referencing, all symbols used in this pamphlet series and their definitions are restated in alphabetical order on pages 23 through 27.

It should be kept in mind that trend charts such as these are really work sheets and are appropriate places for posting notes or data that might otherwise be recorded in a log book and then forgotten. For example, unusual occurrences that might affect plant performance, such as slugs of strong industrial wastes or toxic chemicals entering the plant, heavy rains, power failures, etc. can be noted directly on the trend charts. If this is done, reasons for sudden upsets or process imbalance can be easily identified.

When time permits, trend charts may be expanded to provide plant personnel with greater insights into the operation of their treatment plant. Certain information should be drawn on semi-log paper to help determine relationships between various process parameters, and the moving averages developed to damp out any large day-to-day variations that occur.

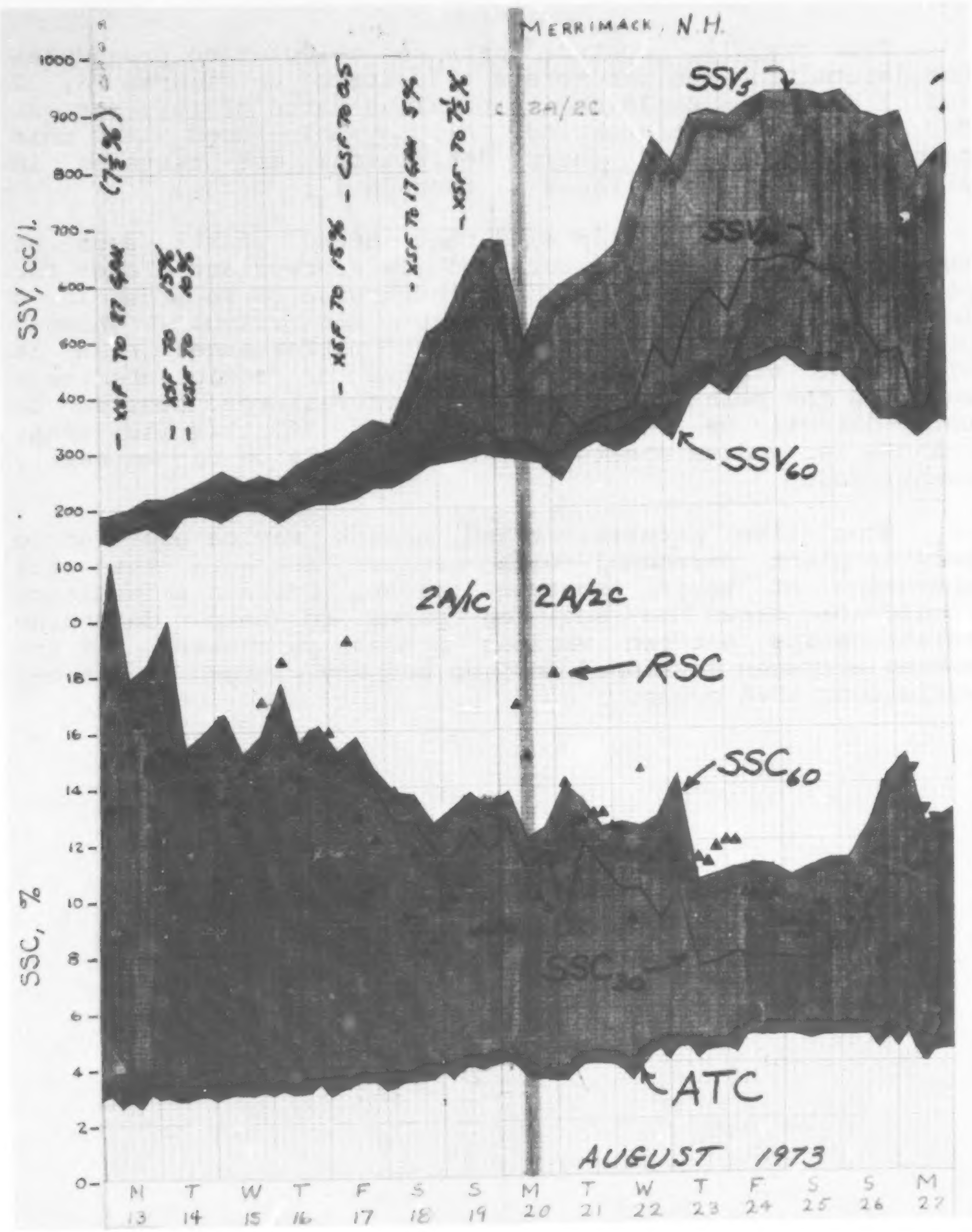


Figure 1

TYPICAL TREND CHART SHOWING SSV & SSC CURVES

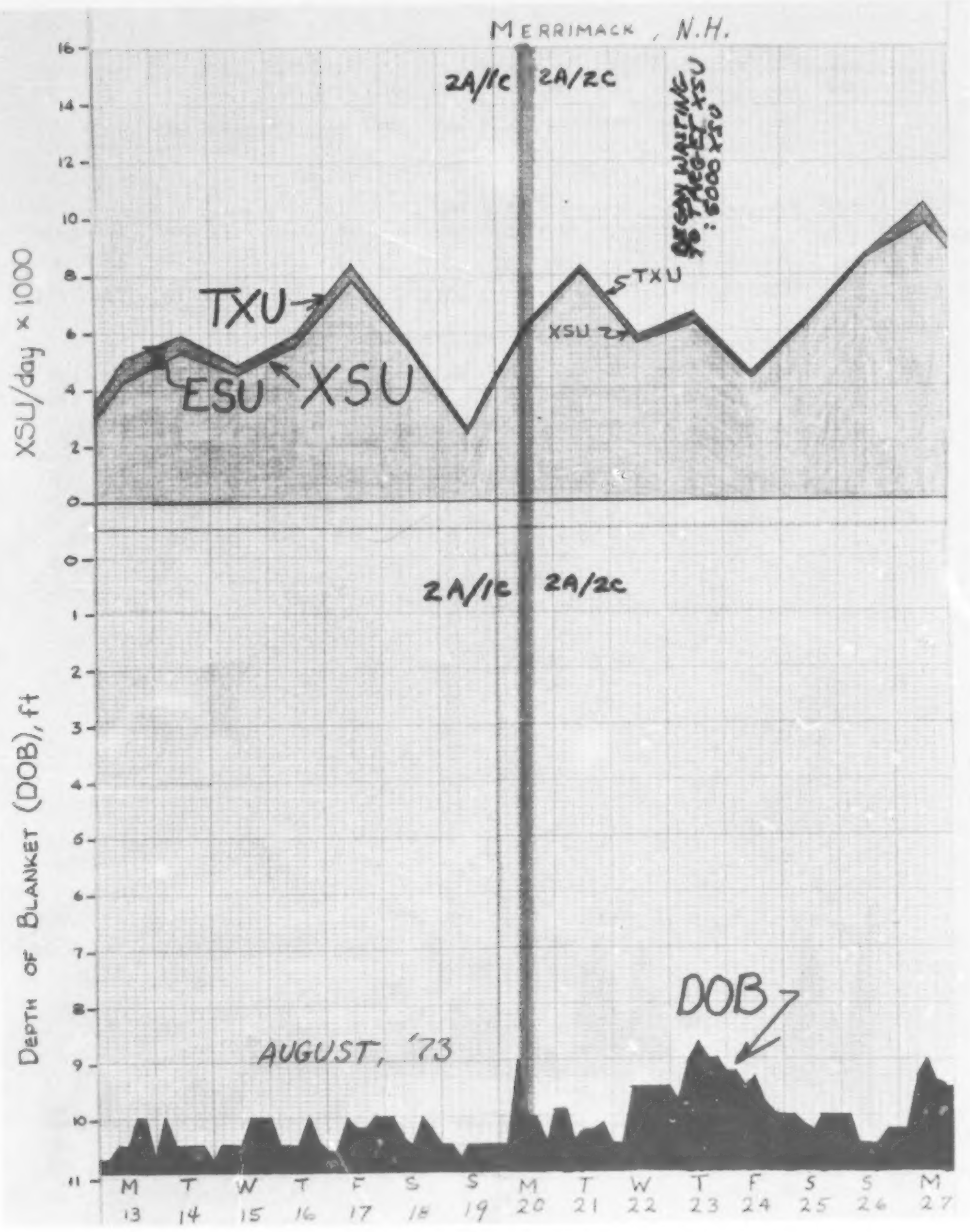
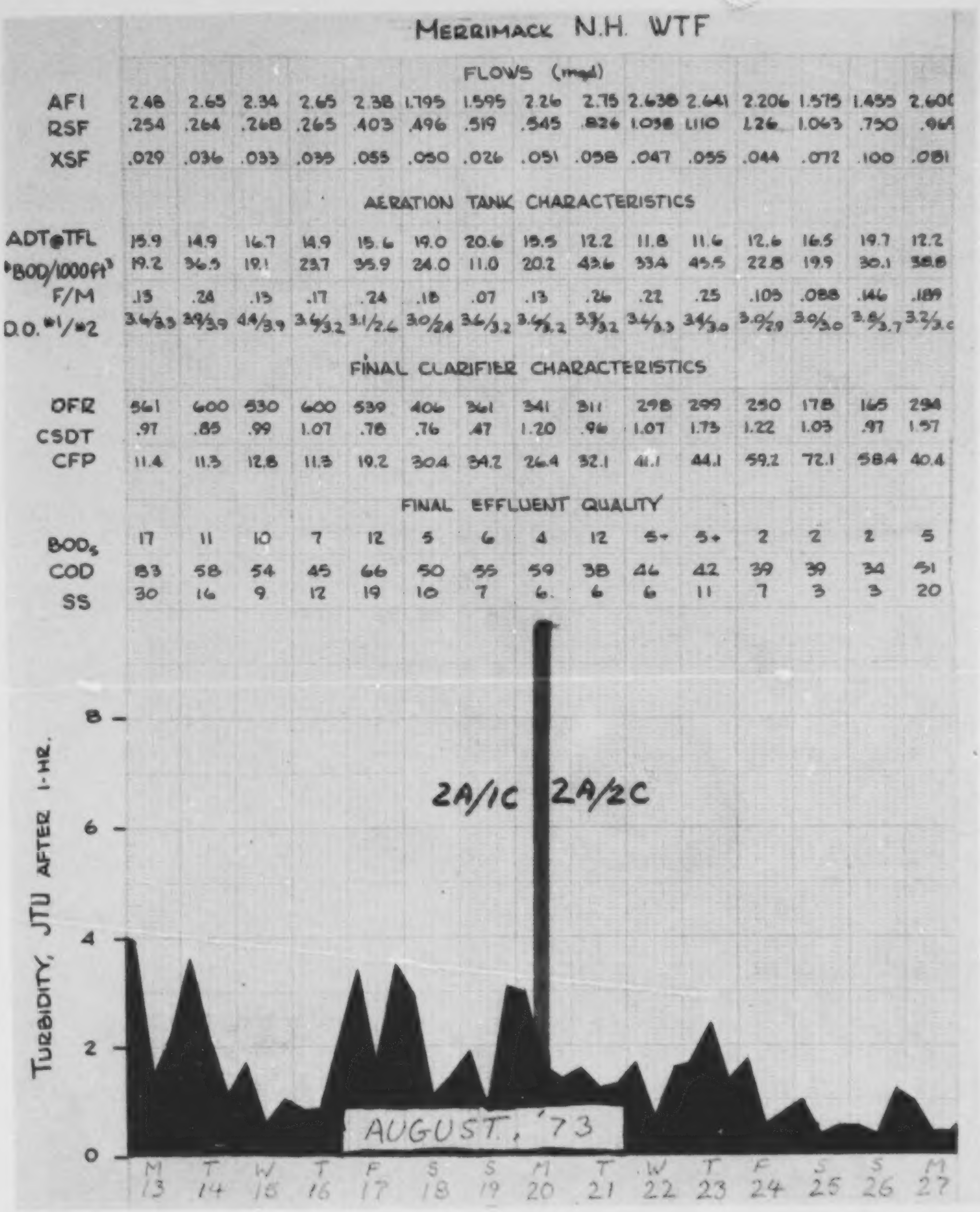


Figure 2

TYPICAL TREND CHART SHOWING XSU/day & DOB CURVES



MERRIMACK N.H. WTF

	FLOWS (mgd)														
AFI	2.48	2.65	2.34	2.65	2.38	1.795	1.595	2.26	2.75	2.638	2.641	2.206	1.575	1.455	2.60
RSF	.254	.264	.268	.265	.403	.496	.519	.545	.826	1.038	1.110	1.26	1.063	.750	.96
XSF	.029	.036	.033	.035	.055	.050	.026	.051	.058	.047	.055	.044	.072	.100	.081
	AERATION TANK CHARACTERISTICS														
ADT@TFL	15.9	14.9	16.7	14.9	15.6	19.0	20.6	15.5	12.2	11.8	11.6	12.6	16.5	19.7	12.2
#BOD/1000ft³	19.2	36.5	19.1	23.7	35.9	24.0	11.0	20.2	43.6	33.4	45.5	22.8	19.9	30.1	38.8
F/M	.15	.24	.13	.17	.24	.18	.07	.13	.26	.22	.25	.105	.088	.146	.189
D.O. #1/#2	3.6/3.3	3.9/3.9	4.4/3.9	3.6/3.2	3.1/2.6	3.0/2.4	3.6/3.2	3.6/3.2	3.3/3.2	3.4/3.3	3.4/3.0	3.0/2.9	3.0/3.0	3.8/3.7	3.2/3.
	FINAL CLARIFIER CHARACTERISTICS														
OFR	561	600	530	600	539	406	361	341	311	298	299	250	178	165	294
CSDT	.97	.85	.99	1.07	.78	.76	.47	1.20	.96	1.07	1.73	1.22	1.03	.97	1.57
CFP	11.4	11.3	12.8	11.3	19.2	30.4	34.2	26.4	32.1	41.1	44.1	59.2	72.1	58.4	40.4
	FINAL EFFLUENT QUALITY														
BOD_5	17	11	10	7	12	5	6	4	12	5+	5+	2	2	2	5
COD	83	58	54	45	66	50	55	59	38	46	42	39	39	34	51
SS	30	16	9	12	19	10	7	6.	6	6	11	7	3	3	20

TURBIDITY, JTU AFTER 1-HR.
8
6
4
2
0
2A/1C
2A/2C
AUGUST, '73
M 13
T 14
W 15
T 16
F 17
S 18
S 19
M 20
T 21
W 22
T 23
F 24
S 25
S 26
M 27

Figure 3

TYPICAL TREND CHART SHOWING FINAL EFFLUENT TURBIDITY AND A TABULATION OF SELECTED PROCESS PARAMETERS

MOVING AVERAGES

Moving averages, especially those for 7- and 28-day intervals, are useful for evaluating process responses to operational control adjustments. The effects of a major change in operating procedures are usually confirmed about a week after the start of the new control procedures. The development of a stable sludge, fully acclimated to the change, usually takes about a month.

The 7-day moving average (7DMA), which reflects the effects of low load Saturdays and Sundays as well as high load Mondays and Tuesdays, permits a realistic review of medium term process response. The 28-day moving average (28DMA) permits evaluation of long-term stabilization performance.

Figure 4 is a graph of sludge wasting data, showing the daily data points, the 7-day moving average, and the 28-day moving average. The individual data points show considerable variation from day to day. By plotting a 7-day moving average, the large variations are smoothed out and the actual trends (increasing or decreasing wasting rates) become more apparent. The 28-day moving average shows the long term trends.

Table 1 includes the daily (24 hour) average, and the 7-day and 28-day moving average data that are plotted on Figure 4.

The 7-day moving average for any given day is the average of the data for that day and the six previous days. For example, from Table 1, the 7-day moving average for 1/4/73 is 1.932. This is obtained by averaging the data for 1/4/73 and the six previous days, starting with 12/29/72:

12/29/72	5.058
12/30/72	0.0
12/31/72	1.374
1/ 1/73	2.459
1/ 2/73	0.960
1/ 3/73	1.598
1/ 4/73	2.076

7 /13.525

1.932 = 7-day moving avg.

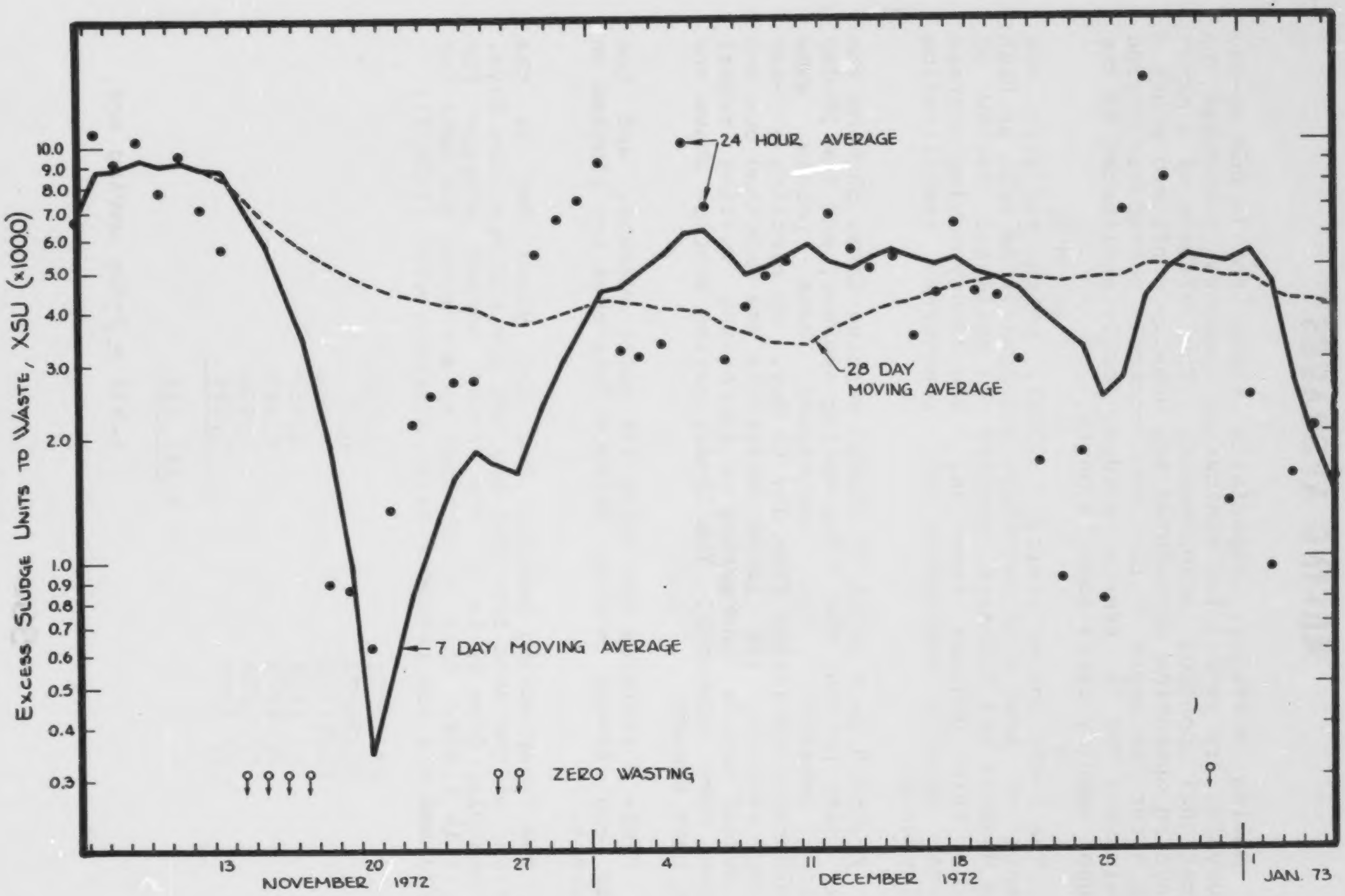


Figure 4

MOVING AVERAGE PLOTS OF XSU DATA

Table 1

24 HOUR AVERAGES, 7 DAY & 28 DAY MOVING AVERAGES OF XSU DATA

DATE	XSU 24HRA	XSU 7DMA	XSU 28DMA
11/ 6/72	BOUNDARY DATE	*	*
11/ 6/72	6.678	6.678= 1	6.678= 1
11/ 7/72	10.873	8.775= 2	8.775= 2
11/ 8/72	9.259	8.937= 3	8.937= 3
11/ 9/72	10.586	9.349= 4	9.349= 4
11/10/72	7.853	9.050= 5	9.050= 5
11/11/72	9.600	9.142= 6	9.142= 6
11/12/72	7.119	8.853	8.853= 7
11/13/72	5.750	8.720	8.465= 8
11/14/72	0.0	7.167	7.524= 9
11/15/72	0.0	5.844	6.772=10
11/16/72	0.0	4.332	6.156=11
11/17/72	0.0	3.210	5.643=12
11/18/72	0.900	1.967	5.278=13
11/19/72	0.870	1.074	4.963=14
11/20/72	0.630	0.343	4.675=15
11/21/72	1.350	0.536	4.467=16
11/22/72	2.160	0.844	4.331=17
11/23/72	2.520	1.204	4.230=18
11/24/72	2.756	1.595	4.152=19
11/25/72	2.772	1.863	4.083=20
11/26/72	0.0	1.738	3.888=21
11/27/72	0.0	1.648	3.712=22
11/28/72	5.508	2.242	3.790=23
11/29/72	6.624	2.880	3.908=24
11/30/72	7.421	3.580	4.048=25
12/ 1/72	9.120	4.492	4.243=26
12/ 2/72	3.230	4.558	4.206=27
12/ 3/72	3.120	5.003	4.167
12/ 4/72	3.326	5.479	4.047
12/ 5/72	10.091	6.133	4.020
12/ 6/72	7.182	6.213	3.945
12/ 7/72	3.084	5.593	3.677
12/ 8/72	4.098	4.876	3.543
12/ 9/72	4.831	5.105	3.373
12/10/72	5.242	5.408	3.306
12/11/72	5.741	5.753	3.306
12/12/72	6.750	5.275	3.547
12/13/72	5.580	5.047	3.746
12/14/72	5.058	5.329	3.927
12/15/72	5.364	5.509	4.118
12/16/72	3.468	5.315	4.210
12/17/72	4.568	5.190	4.335
12/18/72	6.444	5.290	4.542
12/19/72	4.389	4.954	4.651
12/20/72	4.327	4.775	4.729
12/21/72	3.037	4.487	4.747
12/22/72	1.732	3.968	4.711
12/23/72	0.907	3.602	4.645
12/24/72	1.818	3.238	4.710
12/25/72	0.801	2.432	4.738
12/26/72	6.854	2.783	4.786
12/27/72	14.019	4.167	5.051
12/28/72	8.188	4.903	5.078
12/29/72	5.058	5.378	4.933
12/30/72	0.0	5.248	4.817
12/31/72	1.374	5.185	4.755
1/ 1/73	2.459	5.422	4.724
1/ 2/73	0.960	4.580	4.398
1/ 3/73	1.598	2.805	4.199
1/ 4/73	2.076	1.932	4.163
1/ 5/73	1.577	1.435	4.073

LEGEND:

XSU = EXCESS SLUDGE UNITS WASTED (IN 1,000 SLUDGE UNITS)
24HRA = 24-HOUR (DAILY) AVERAGE
7DMA = 7-DAY MOVING AVERAGE
28DMA = 28-DAY MOVING AVERAGE

BOUNDARY DATE = THE FIRST DAY OF DATA INCLUDED IN THE CALCULATIONS

* = INDICATES THE NUMBER OF DAILY DATA POINTS INCLUDED IN THE CALCULATIONS, WHERE LESS THAN 7 (OR 28) ARE AVAILABLE.

Similarly, the 7-day moving average for the next day, 1/5/73, is the average of the data for that day and the six previous days, starting with 12/30/72:

12/30/72	0.0
12/31/72	1.374
1/ 1/73	2.459
1/ 2/73	0.960
1/ 3/73	1.598
1/ 4/73	2.076
1/ 5/73	1.577

7 /10.044

1.435 = 7-day moving avg.

The 7-day moving average for 1/5/73 could also be calculated easily from the previous day's calculations by subtracting the data for 12/29/72 (5.058) from the previous day's subtotal (13.525), adding the data for 1/5/73 (1.577) and dividing by 7:

13.525
- 5.058 (12/29/72)

8.467
+ 1.577 (1/5/73)

7 /10.044

1.435 = 7-day moving avg.

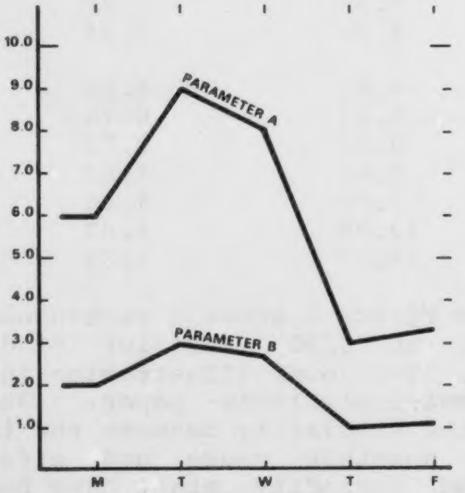
A 28-day moving average is derived by the same type of calculation.

When working with a new set of data, such as at the start of a new operational control phase, it is necessary to start with a progressive average (rather than a 7-day moving average) until seven days of data are included. Note that the 7 DMA column on Table 1 does not start with a true 7-day moving average, since the time period covered is less than seven days. The initial values for the first 6 days shown in the 7 DMA column are progressive averages until 11/12/72, at which point they become true 7-day moving averages. Similarly, the initial values for the first 27 days in the 28 DMA column are progressive averages until 12/3/72, when they become 28-day moving averages.

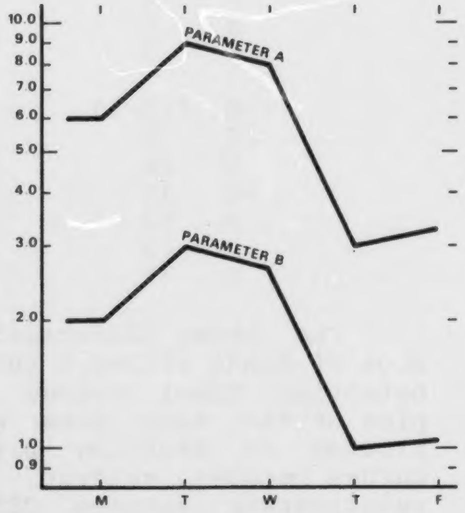
SEMI-LOGARITHMIC PLOTS

Process responses (SSV, ATC, SSC, turbidity, etc.) to control adjustments are normally plotted on a test-by-test basis to permit process evaluation. Semi-logarithmic plots are useful when one wishes to compare the rate of change of various parameters to a process adjustment because it permits direct observation of rate changes between the parameters regardless of their magnitudes.

Consider the following hypothetical example as displayed on the two graphs below. Two identical data sets (A and B) are plotted on each graph. The left graph is drawn on rectangular coordinate paper, the right on semi-logarithmic paper. Note how readily the trend similarity becomes apparent from a comparison of the semi-logarithmic curves. In this example, the plotted parameters have identical slopes and remain parallel to each other. The rectangular plot of the same parameters does not readily display that the rate changes, defined by their slopes, are identical. The probable relationship between parameters A and B might have been overlooked if only rectangular coordinate paper had been used.



RECTANGULAR PLOT



SEMI-LOGARITHMIC PLOT

Now consider two plots drawn from the actual plant data shown below:

TABLE 2

Day/Date	Turb (JTU)	CSDT (hrs)
M 12/18/72	9.93	0.69
T 19	9.53	1.09
W 20	9.13	1.73
T 21	13.00	3.32
F 22	12.33	3.17
S 23	13.53	2.85
S 24	13.87	3.96
M 12/25/72	21.67	4.04
T 26	17.33	4.61
W 27	19.00	3.36
T 28	20.00	3.29
F 29	17.67	2.81
S 30	13.30	2.88
S 31	9.80	2.29
M 1/1/73	6.90	1.36
T 2	6.30	1.10
W 3	6.10	0.84
T 4	5.77	0.78
F 5	8.10	0.92
S 6	9.25	0.92
S 7	6.57	0.91
M 1/8/73	6.47	0.69
T 9	5.03	0.74
W 10	3.67	0.79
T 11	5.40	1.43
F 12	5.90	1.25
S 13	10.90	1.49
S 14	10.47	1.39

The upper illustration on Figure 5 shows a rectangular plot of final effluent turbidity and CSDT (Clarifier Sludge Detention Time) versus Time. The lower illustration is a plot of the same data on semi-logarithmic paper. When plotted on semi-log paper, the similarity between the two curves becomes evident. The possible cause and effect relationship between CSDT and turbidity might have been overlooked if only rectangular paper had been used.

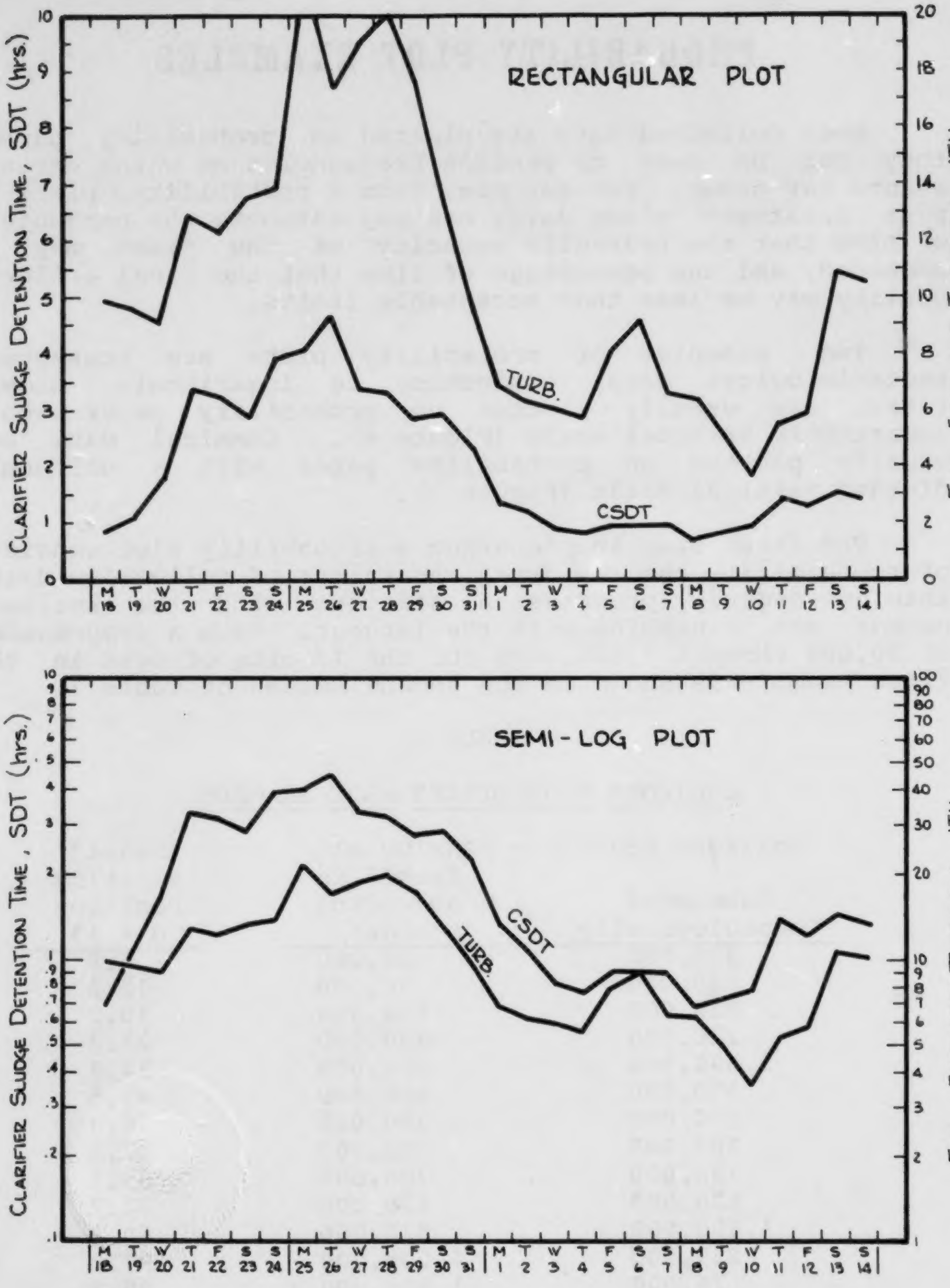


Figure 5

COMPARISON OF RECTANGULAR AND SEMI-LOGARITHMIC PLOTS

PROBABILITY PLOT EXAMPLES

When collected data are plotted on probability paper, they can be used to predict frequencies at which certain events may occur. For example, from a probability plot of past treatment plant data, one may estimate the percentage of time that the hydraulic capacity of the plant may be exceeded, and the percentage of time that the final effluent quality may be less than acceptable limits.

Two examples of probability plots are presented. Bacteriological data, conforming to logarithmic growth rates, are usually plotted on probability paper with a logarithmic vertical scale (Figure 6). Chemical data are usually plotted on probability paper with a uniformly divided vertical scale (Figure 7).

The first step in preparing a probability plot consists of reorganizing the raw data, regardless of collection date, into an orderly progression starting with the smallest number and finishing with the largest. Such a progression of 50,000 through 1,600,000+ for the 13 bits of data in the first example is shown in the second column of Table 3.

TABLE 3

COLIFORM PROBABILITY PLOT EXAMPLE

Coliform Density - MPN/100 ml		"Exact" Plotting Position
Tabulated Chronologically	Ranked in Ascending Order	N = 13
330,000	50,000	4.8
50,000	78,000	12.2
820,000	110,000	19.2
220,000	130,000	27.3
1,600,000	220,000	34.9
350,000	230,000	42.5
110,000	330,000	50.0
700,000	350,000	57.5
130,000	700,000	65.1
820,000	820,000	72.7
1,600,000 +	820,000	80.2
230,000	1,600,000	87.8
78,000	1,600,000 +	95.2

NOTE: 541,000 = Arithmetic Mean
330,000 = Probability Mean (Fig. 7)

The plotting position, shown in the third column of Table 3 for each data item, can then be obtained directly from Table 4 if 50 or less data points are to be plotted. Plotting positions for sample sizes greater than 50 can be calculated according to the formula on Table 4, page 18. For this sample size of 13, the plotting positions ranged from "less than" 4.8% of the time for 50,000 to "less than" 95.2% of the time for 160,000+.

The coliform concentrations were then plotted according to their respective plotting positions. The completed probability plot of the coliform data is illustrated in Figure 6.

At first glance, the large and irregular day-to-day differences in coliform concentrations shown in column one of Table 3 appeared irreconcilable. But the probability plot of this same information displayed the data in an orderly fashion and permitted logical evaluation of the survey results. As shown on Figure 6, the mean density was 330,000 MPN/100 ml and it could be expected that the concentration would most probably equal or exceed 58,000 90% of the time, and equal or exceed 1,850,000 10% of the time.

Figure 7 is a probability plot of final effluent BOD5 concentrations and aeration tank BOD5 loadings at an activated sludge plant. The data were arranged as in the previous example, and the plotting positions were determined from the formula on Table 4. In this example normal (rectangular coordinate) probability paper was used.

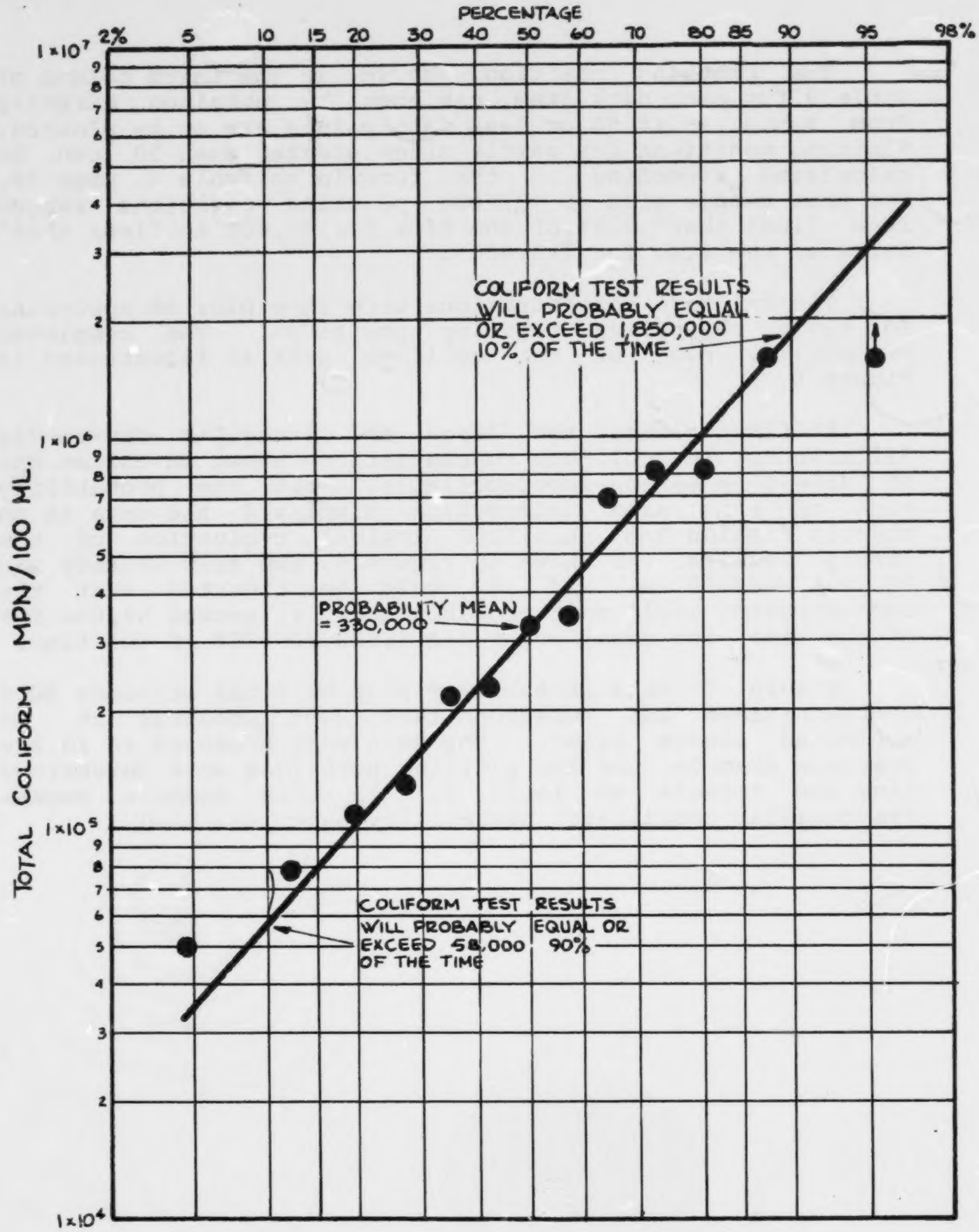


Figure 6

SEMI-LOGARITHMIC PROBABILITY PLOT OF COLIFORM DATA

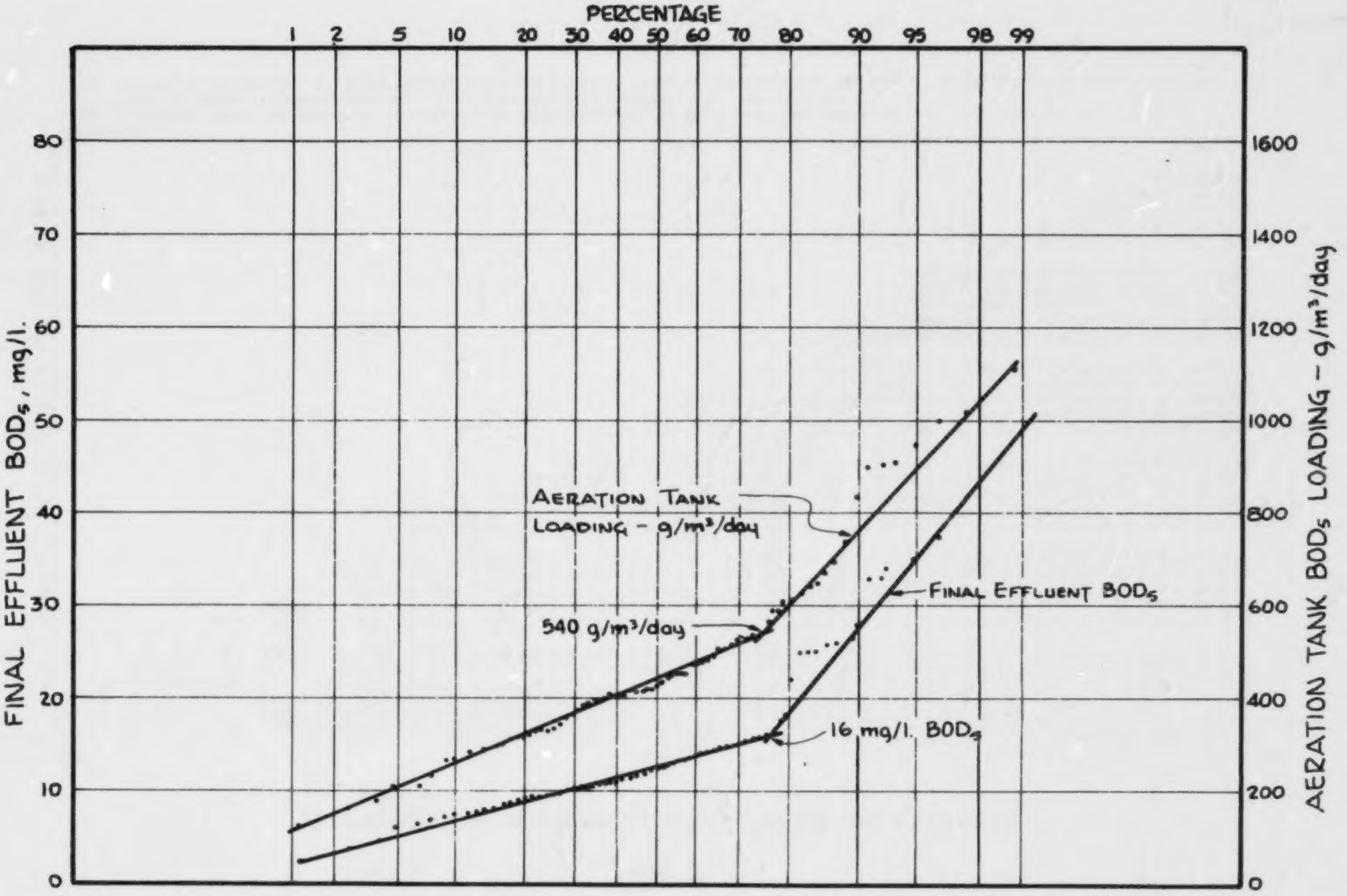


Figure 7

RECTANGULAR PROBABILITY PLOT OF LOADING AND BOD DATA

Table 4

PLOTTING POSITIONS FOR NORMAL PROBABILITY PAPER

Ordinal No.	Sample Size																														Ordinal No.
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	
1	28.6	19.9	15.2	12.2	10.3	8.8	7.7	6.9	6.2	5.6	5.2	4.8	4.4	4.1	3.9	3.6	3.4	3.3	3.1	2.9	2.8	2.7	2.6	2.4	2.4	2.3	2.2	2.1	2.1	2.0	1
2	71.4	50.0	38.3	31.0	26.0	22.5	19.7	17.6	15.8	14.4	13.2	12.2	11.4	10.6	9.9	9.4	8.9	8.4	8.0	7.7	7.2	6.8	6.7	6.4	6.2	5.9	5.7	5.5	5.3	5.2	2
3		80.1	61.7	50.0	42.0	36.2	31.8	28.4	25.6	23.3	21.4	19.8	18.4	17.2	16.1	15.2	14.3	13.6	12.9	12.3	11.7	11.3	10.7	10.4	9.9	9.5	9.2	8.9	8.7	8.4	3
4			84.8	69.0	58.0	50.0	43.9	39.2	35.3	32.2	29.6	27.3	25.4	23.7	22.3	21.0	19.8	18.8	17.9	17.1	16.4	15.6	14.9	14.2	13.8	13.3	12.7	12.3	11.9	11.5	4
5				87.8	74.0	63.8	56.1	50.0	45.1	41.1	37.8	34.9	32.4	30.3	28.4	26.8	25.3	24.0	22.8	21.8	20.6	19.8	18.9	18.1	17.6	16.9	16.4	15.9	15.2	14.7	5
6					89.7	77.5	68.2	60.8	54.9	50.0	45.9	42.5	39.5	36.5	34.6	32.6	30.8	29.2	27.8	26.4	25.1	24.2	23.3	22.4	21.5	20.6	19.8	19.2	18.7	17.9	6
7						91.2	80.3	71.6	64.7	58.9	54.1	50.0	46.5	43.4	40.7	38.4	36.3	34.4	32.7	31.2	29.8	28.4	27.4	26.1	25.1	24.2	23.3	22.7	21.8	21.2	7
8							92.3	82.4	74.4	67.8	62.2	57.5	53.5	50.0	46.9	44.2	41.8	39.6	37.6	35.9	34.1	32.6	31.6	30.2	29.1	28.1	27.1	26.1	25.1	24.6	8
9								93.1	84.2	76.7	70.4	65.1	60.5	56.6	53.1	50.0	47.2	44.8	42.6	40.5	38.6	37.1	35.6	34.1	33.0	31.6	30.5	29.5	28.4	27.4	9
10									93.8	85.6	78.6	72.7	67.6	63.1	59.3	55.8	52.8	50.0	47.5	45.2	43.3	41.3	39.7	38.2	36.7	35.2	34.1	33.0	31.9	30.9	10
11										94.4	86.8	80.2	74.6	69.7	65.4	61.6	58.2	55.2	52.5	50.0	47.6	45.6	43.6	42.1	40.5	39.0	37.4	36.3	35.2	34.1	11
12											94.8	87.8	81.6	76.3	71.6	67.4	63.7	60.4	57.4	54.8	52.4	50.0	48.0	46.0	44.4	42.5	41.3	39.7	38.6	37.1	12
13												95.2	88.6	82.8	77.7	73.2	69.2	65.6	62.4	59.5	56.7	54.4	52.0	50.0	48.0	46.4	44.8	43.3	41.7	40.5	13
14													95.6	89.4	83.9	79.0	74.7	70.8	67.3	64.1	61.4	58.7	56.4	54.0	52.0	50.0	48.4	46.4	45.2	43.6	14
15														95.9	90.1	84.8	80.2	76.0	72.2	68.8	65.9	62.9	60.3	57.9	55.6	53.6	51.6	50.0	48.4	46.8	15
16															96.1	90.6	85.7	81.2	77.2	73.6	70.2	67.4	64.4	61.8	59.5	57.5	55.2	53.6	51.6	50.0	16
17																96.4	91.1	86.4	82.1	78.2	74.9	71.6	68.4	65.9	63.3	61.0	58.7	56.7	54.8	53.2	17
18																	96.6	91.6	87.1	82.9	79.4	75.8	72.6	69.8	67.0	64.8	62.6	60.3	58.3	56.4	18
19																		96.7	92.0	87.7	83.6	80.2	76.7	73.9	70.9	68.4	65.9	63.7	61.4	59.5	19
20																			96.9	92.3	88.3	84.4	81.1	77.6	74.9	71.9	69.5	67.0	64.8	62.9	20
21																				97.1	92.8	88.7	85.1	81.9	78.5	75.8	72.9	70.5	68.1	65.9	21
22																					97.2	93.2	89.3	85.8	82.4	79.4	76.7	73.9	71.6	69.1	22
23																						97.3	93.3	89.6	86.2	83.1	80.2	77.3	74.9	72.6	23
24																							97.4	93.6	90.1	86.7	83.6	80.8	78.2	75.4	24
25																								97.6	93.8	90.5	87.3	84.1	81.3	78.8	25
26																									97.6	94.1	90.8	87.7	84.8	82.1	26
27																										97.7	94.3	91.1	88.1	85.3	27
28																											97.8	94.5	91.3	88.5	28
29																												97.9	94.7	91.6	29
30																													97.9	94.8	30
31																														98.0	31

References:

(1) Statistical Tables for Biological Agricultural and Medical Research, by Fisher and Yates, Hafner Pub. Co., '63, Table XX, 94-95
(2) Tables of Normal Probability Functions, U. S. Government Printing Office, '53, Table I, 2-338
(3) Pearson, E. and Hartley, H., Biometrika Tables for Statisticians Volume I, Cambridge University Press, '54, Table 28, 175, Table 1, 104-110

Table 4 (Cont.)

PLOTTING POSITIONS FOR NORMAL PROBABILITY PAPER

Ordinal No.	32	33	34	35	36	37	38	39	40	41
1	1.92	1.88	1.83	1.76	1.70	1.66	1.62	1.58	1.54	1.50
2	4.9	4.8	4.6	4.6	4.5	4.3	4.2	4.1	4.0	3.9
3	8.1	7.8	7.6	7.4	7.2	6.9	6.8	6.7	6.4	6.3
4	11.1	10.9	10.6	10.2	10.0	9.7	9.4	9.2	9.0	8.7
5	14.2	13.8	13.3	13.1	12.7	12.3	12.1	11.7	11.5	11.1
6	17.4	16.9	16.4	15.9	15.4	15.2	14.7	14.2	14.0	13.6
7	20.6	19.8	19.2	18.7	18.1	17.9	17.4	16.9	16.4	16.1
8	23.6	23.0	22.4	21.5	20.9	20.3	19.8	19.5	18.9	18.4
9	26.8	25.8	25.1	24.5	23.6	23.3	22.7	22.1	21.5	20.9
10	29.8	28.8	28.1	27.4	26.4	25.8	25.1	24.5	23.9	23.3
11	33.0	31.9	30.9	30.2	29.5	28.4	27.8	27.1	26.4	25.8
12	35.9	34.8	34.1	33.0	31.9	31.2	30.5	29.5	28.8	28.1
13	39.0	37.8	36.7	35.9	34.8	33.7	33.0	32.3	31.2	30.5
14	42.1	40.9	39.7	38.6	37.4	36.7	35.6	34.8	33.7	33.0
15	45.2	44.0	42.9	41.3	40.5	39.4	38.2	37.1	36.3	35.6
16	48.4	46.8	45.6	44.4	43.3	42.1	40.9	39.7	39.0	37.8
17	51.6	50.0	48.4	47.2	46.0	44.4	43.6	42.5	41.3	40.1
18	54.8	53.2	51.6	50.0	48.8	47.2	46.0	44.8	43.6	42.9
19	57.9	56.0	54.4	52.8	51.2	50.0	48.8	47.6	46.4	45.2
20	61.0	59.1	57.1	55.6	54.0	52.8	51.2	50.0	48.8	47.6
21	64.1	62.2	60.3	58.7	56.7	55.6	54.0	52.4	51.2	50.0
22	67.0	65.2	63.3	61.4	59.5	57.9	56.4	55.2	53.6	52.4
23	70.2	68.1	65.9	64.1	62.6	60.6	59.1	57.5	56.4	54.8
24	73.2	71.2	69.1	67.0	65.2	63.3	61.8	60.3	58.7	57.1
25	76.4	74.2	71.9	69.8	68.1	66.3	64.4	62.9	61.0	59.9
26	79.4	77.0	74.9	72.6	70.5	68.8	67.0	65.2	63.7	62.2
27	82.6	80.2	77.6	75.5	73.6	71.6	69.5	67.7	66.3	64.4
28	85.8	83.1	80.8	78.5	76.4	74.2	72.2	70.5	68.8	67.0
29	88.9	86.2	83.6	81.3	79.1	76.7	74.9	72.9	71.2	69.5
30	91.9	89.1	86.7	84.1	81.9	79.7	77.3	75.5	73.6	71.9
31	95.1	92.2	89.4	86.9	84.6	82.1	80.2	77.9	76.1	74.2
32	98.08	95.2	92.6	89.8	87.3	84.8	82.6	80.5	78.5	76.7
33		98.12	95.4	92.6	90.0	87.7	85.3	83.1	81.1	79.1
34			98.17	95.4	92.8	90.3	87.9	85.8	83.6	81.6
35				98.26	95.5	93.1	90.6	88.3	86.0	83.9
36					98.30	95.7	93.2	90.8	88.5	86.4
37						98.34	95.8	93.3	91.0	88.9
38							98.38	95.9	93.6	91.3
39								98.42	96.0	93.7
40									98.46	96.1
41										98.50
42										
43										
44										
45										
46										
47										
48										
49										
50										

Ordinal No.	42	43	44	45	46	47	48	49	50
1	1.46	1.43	1.39	1.36	1.32	1.32	1.29	1.25	1.22
2	3.8	3.7	3.6	3.5	3.4	3.4	3.3	3.2	3.2
3	6.2	6.1	5.8	5.7	5.6	5.5	5.4	5.3	5.2
4	8.5	8.4	8.1	7.9	7.8	7.6	7.5	7.4	7.2
5	10.9	10.6	10.4	10.2	10.0	9.7	9.5	9.3	9.2
6	13.3	12.9	12.7	12.3	12.1	11.9	11.7	11.3	11.1
7	15.6	15.4	14.9	14.7	14.2	14.0	13.8	13.3	13.1
8	18.1	17.6	17.1	16.9	16.4	16.1	15.9	15.4	15.2
9	20.3	20.0	19.5	18.9	18.7	18.1	17.9	17.4	17.1
10	22.7	22.4	21.8	21.2	20.9	20.3	20.0	19.5	19.2
11	25.1	24.5	23.9	23.8	23.0	22.4	22.1	21.5	21.2
12	27.4	26.8	26.1	25.8	25.1	24.5	24.2	23.6	23.0
13	29.8	29.1	28.4	27.8	27.4	26.7	26.1	25.5	25.1
14	32.3	31.6	30.9	30.2	29.5	28.8	28.1	27.8	27.1
15	34.5	33.7	33.0	32.3	31.6	30.9	30.2	29.8	29.1
16	37.1	35.9	35.2	34.5	33.7	33.0	32.3	31.6	31.2
17	39.4	38.6	37.4	36.7	35.9	35.2	34.5	33.7	33.0
18	41.7	40.9	39.7	39.0	38.2	37.4	36.7	35.9	35.2
19	44.0	43.3	42.1	41.3	40.1	39.4	38.6	37.8	37.1
20	46.4	45.2	44.4	43.3	42.5	41.7	40.5	39.7	39.0
21	48.8	47.6	46.4	45.6	44.4	43.6	42.9	41.7	40.9
22	51.2	50.0	48.8	47.6	46.8	45.6	44.8	44.0	42.9
23	53.6	52.4	51.2	50.0	48.8	48.0	46.8	46.0	44.8
24	56.0	54.8	53.6	52.4	51.2	50.0	48.8	48.0	46.8
25	58.3	56.7	55.6	54.4	53.2	52.0	51.2	50.0	48.8
26	60.6	59.1	57.9	56.7	55.6	54.4	53.2	52.0	51.2
27	62.9	61.4	60.3	58.7	57.5	56.4	55.2	54.0	53.2
28	65.5	64.1	62.6	61.0	59.9	58.3	57.1	56.0	55.2
29	67.7	66.3	64.8	63.3	61.8	60.6	59.5	58.3	57.1
30	70.2	68.4	67.0	65.5	64.1	62.6	61.4	60.3	59.1
31	72.6	70.9	69.1	67.7	66.3	64.8	63.3	62.2	61.0
32	74.9	73.2	71.6	69.8	68.4	67.0	65.5	64.1	62.9
33	77.3	75.5	73.9	72.2	70.5	69.1	67.7	66.3	64.8
34	79.7	77.6	76.1	74.2	72.6	71.2	69.8	68.4	67.0
35	81.9	80.0	78.2	76.4	74.9	73.2	71.9	70.2	68.8
36	84.4	82.4	80.5	78.8	77.0	75.5	73.9	72.2	70.9
37	86.7	84.6	82.9	81.1	79.1	77.6	75.8	74.5	72.9
38	89.1	87.1	85.1	83.1	81.3	79.7	77.9	76.4	74.9
39	91.5	89.4	87.3	85.3	83.6	81.9	80.0	78.5	77.0
40	93.8	91.6	89.6	87.7	85.8	83.9	82.1	80.5	78.8
41	96.2	93.9	91.9	89.8	87.9	86.0	84.1	82.6	80.8
42	98.54	96.3	94.2	92.1	90.0	88.1	86.2	84.6	82.9
43		98.57	96.4	94.3	92.2	90.3	88.3	86.7	84.8
44			98.61	96.5	94.4	92.4	90.5	88.7	86.9
45				98.64	96.6	94.5	92.5	90.7	88.9
46					98.68	96.6	94.6	92.6	90.8
47						98.68	96.7	94.7	92.8
48							98.71	96.8	94.8
49								98.75	96.8
50									98.78

For sample sizes larger than 50 plotting position is estimated as:

$$\frac{100\,(\text{ordinal number} - 0.5)}{\text{sample size}}$$

EXAMPLE:

Sample Size 51	Ordinal number
$0.98 = \frac{100(1-0.5)}{51}$	1
$2.94 = \frac{100(2-0.5)}{51}$	2
.	.
.	.
$99.02 = \frac{100(51-0.5)}{51}$	51

TESTING EQUIPMENT

Some special equipment for operational control testing are used in the NFIC-C Procedures. Basically a settlometer, centrifuge, turbidimeter, and optical sludge blanket finder are needed.

The construction of a typical sludge blanket finder is shown in Figure 8. Approximate prices (1973) and types of control test equipment that have been used by the Waste Treatment Branch are as follows:

Blanket Finder Parts

Site Glass - Part No. 4045 for 1 1/2" pipe $5.00

Gitz Mfg. Co.
1846 South Kilbourn Ave.
Chicago, Illinois 60623

Use Schedule 40 aluminum pipe. Tape the tube every 0.5 ft. starting at the site glass to facilitate reading the blanket depth. Faster readings may be obtained if distinctive markings are used at the 5 ft. and 10 ft. points.

Mallory Direct Reading Settlometer

5" dia. x 7" high, 2 liter graduated cyl. $24.00

Scientific Glass Apparatus Co.
735 Broad Street
Bloomfield, New Jersey 07003

Turbidimeter

Hach Model 2100-A Laboratory Turbidimeter $525.00

Hach Chemical Co.
Box 907
Ames, Iowa 50010

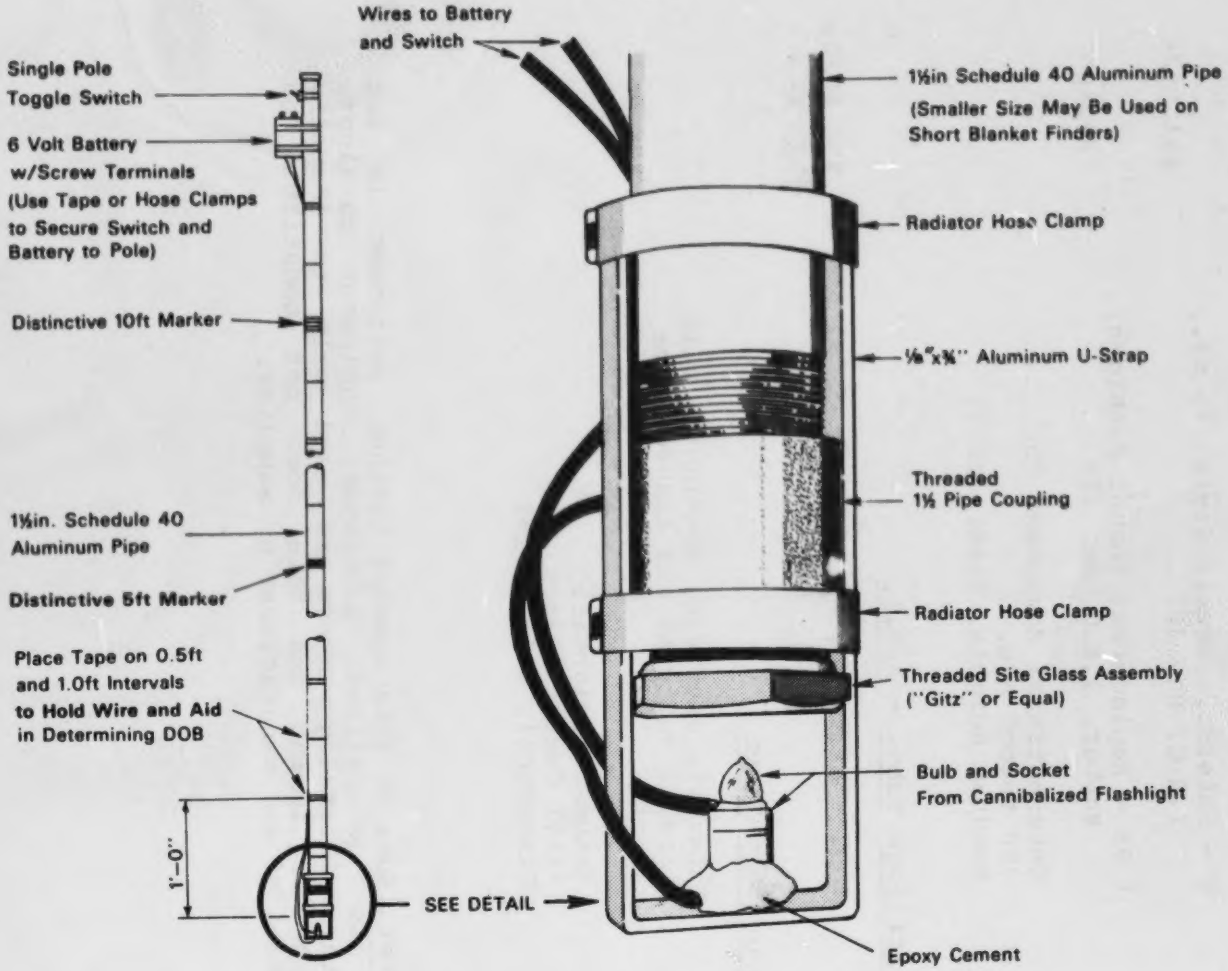

Wires to Battery and Switch
Single Pole Toggle Switch
6 Volt Battery w/Screw Terminals (Use Tape or Hose Clamps to Secure Switch and Battery to Pole)
Distinctive 10ft Marker
1½in. Schedule 40 Aluminum Pipe
Distinctive 5ft Marker
Place Tape on 0.5ft and 1.0ft Intervals to Hold Wire and Aid in Determining DOB
1'–0"
SEE DETAIL
1½in Schedule 40 Aluminum Pipe (Smaller Size May Be Used on Short Blanket Finders)
Radiator Hose Clamp
⅛"x¾" Aluminum U-Strap
Threaded 1½ Pipe Coupling
Radiator Hose Clamp
Threaded Site Glass Assembly ("Gitz" or Equal)
Bulb and Socket From Cannibalized Flashlight
Epoxy Cement

Figure 8

SLUDGE BLANKET FINDER

Clinical Centrifuge, I.E.C. No. 428	$208.00
1 - Head, Trunion, 6-place, 15 ml., I.E.C. No. 221	$59.00
6 - Shields, Cornell Style, 15 ml., I.E.C. No. 303	$31.50/6
1 Pk - Replacement Thrust Cushions, Rubber, I.E.C. No. 570	$2.40

International Equipment Co.
300 Second Ave.
Needham Heights, Mass. 02194

Centrifuge Tubes - A.P.I.

1 Dz - Kimax No. 45170	$30.00/Dz

Laboratory Timer

Interval, electric, 60-minute, with alarm, 2 switches and elapsed time circuit	$35.00

Matheson Scientific
12101 Centron Place
Cincinnati, Ohio 45246

Note: Some of this special testing equipment is not listed in generalized laboratory equipment catalogs. Manufacturers' catalog numbers are used only to identify types of equipment and this does not constitute an endorsement of any manufacturer or supplier.

SYMBOLS AND TERMINOLOGY USED IN ACTIVATED SLUDGE PROCESS CALCULATIONS

AAG - Aeration Age (Number of days sludge subjected to aeration)

ADT - Aeration Tank Detention Time (Hours)

AFI - Aeration Tank Wastewater Flow-In (mgd or cu m/day)

AGE - Sludge Age (Days)

ASDT - Aeration Tank Sludge Detention Time (Hours)

ASA - Aeration Tank Surface Area

ASF - Aeration Tank Surface Area (Square Feet)

ASM - Aeration Tank Surface Area (Square Meters)

ASU - Aeration Tank Sludge Units

ATC - Aeration Tank Concentration (% by Centrifuge)

ATCm - Mean Aeration Tank Concentration

ATCn - Aeration Tank Concentration (Final Bay)

AV - Aeration Tank Volume

AVF - Aeration Tank Volume (Cubic Feet)

AVG - Aeration Tank Volume (Gallons)

AVM - Aeration Tank Volume (Cubic Meters)

AWDT - Aeration Tank Waste Detention Time

BLT - Sludge Blanket Thickness

BLV - Sludge Blanket Volume

BOD - Biochemical Oxygen Demand (5-day unless stated otherwise)

BODd - Calculated Net Five-Day Biochemical Oxygen Demand of waste water and the "liquid portion" of the return sludge at the aeration tank entrance (diluted waste water)

BODi - Five-Day Biochemical Oxygen Demand of the waste water entering (in) the aeration tank

BODo - Five-Day Biochemical Oxygen Demand of the final clarifier effluent (out)

CDT - Final Clarifier Detention Time (Hours)

CFI - Final Clarifier Flow - In (mgd or cu m/day)

CFL - Final Clarifier Sludge Floor Loading

CFO - Final Clarifier Flow - Out (mgd or cu m/day)

CFP - Final Clarifier Sludge Flow Percentage

COD - Chemical Oxygen Demand

CSA - Final Clarifier Surface Area (Square Feet)

CSM - Final Clarifier Surface Area (Square Meters)

CSC - Final Clarifier Sludge Concentration

CSDT - Final Clarifier Sludge Detention Time (Hours)

CSF - Final Clarifier Sludge Flow (RSF + XSF)

CSFD - Final Clarifier Sludge Flow Demand

CSU - Final Clarifier Sludge Units

CSUI - Final Clarifier Sludge Units - In

CSUO - Final Clarifier Sludge Units - Out of Clarifier

CV - Final Clarifier Volume

CVF - Final Clarifier Volume (Cubic Feet)

CVG - Final Clarifier Volume (Gallons)

CVM - Final Clarifier Volume (Cubic Meters)

CWD - Final Clarifier Mean Water Depth

DOB - Depth Of Sludge Blanket

ESU - Final Effluent Sludge Units (Total Suspended Solids lost in Final Effluent expressed as SLU)

FEC - Final Effluent Concentration (Total Suspended Solids converted to % by Centrifuge - FETSS/WCR)

FET - Final Effluent Turbidity (JTU)

FETSS - Final Effluent Total Suspended Solids (mg/l)

j - Suffix Notation (Used to indicate a particular aeration tank bay)

j-1 - Suffix Notation (Used to indicate the bay preceding the bay of reference, j)

JTU - Jackson Turbidity Units

LOD - Load (lbs BOD/day to aeration tanks)

LODk - Load (kg BOD/day to aeration tanks)

MLTSS - Mixed Liquor Total Suspended Solids (mg/l)

MLVSS - Mixed Liquor Volatile Suspended Solids (mg/l)

OFR - Final Clarifier Surface Overflow Rate (Gal/day/sq ft or cu m/day/sq m)

PEC - Primary Effluent Concentration (PETSS / WCR)

PET - Primary Effluent Turbidity (JTU)

PETSS - Primary Effluent Total Suspended Solids (mg/l)

PFI - Primary Flow Into Primary Clarifiers

PFO - Primary Flow Out Of Primary Clarifiers

PSF - Primary Sludge Flow (mgd or cu m/day)

PSAF - Primary Clarifier Surface Area (Square Feet)

PSAM - Primary Clarifier Surface Area (Square Meters)

PVF - Primary Clarifier Volume (Cubic Feet)

PVG - Primary Clarifier Volume (Gallons)

PVM - Primary Clarifier Volume (Cubic Meters)

RFD - Return Sludge Flow Demand

RFP - Return Sludge Flow Percentage (RSF as a % of AFI by meter)

RSC - Return Sludge Concentration (% by Centrifuge)

RSF - Return Sludge Flow (mgd or cu m/day)

RSP - Return Sludge Percentage (Calculated from ATC, RSC, and PEC)

RSTSS - Return Sludge Total Suspended Solids (mg/l)

RSU - Return Sludge Units (To aeration tanks)

RSVSS - Return Sludge Volatile Suspended Solids (mg/l)

SAH - Sludge Aeration Hours (Hours/day in aeration tank)

SAP - Sludge Aeration Hours In Percent Of Day

SCR - Sludge Concentration Ratio (SSC60 / RSC)

SCY - Sludge Cycles (per day)

SDR - Sludge Distribution Ratio (ASU / CSU)

SLR - Sludge Ratio (RSC / ATC)

SLU - Sludge Units

SSC - Settled Sludge Concentration (% by Centrifuge)

SST - Settled Sludge Time

SSV - Settled Sludge Volume

TDT - Total Sludge Detention Time (ADT + SDT in Hours)

TFI - Sludge Thickener Flow-In (mgd or cu m/day)

TFL - Total Flow (mgd or cu m/day out of aeration tank)

TFO - Thickener Flow Out (mgd or cu m/day)

TKR - Tank Ratio (AVG / CVG)

TSF - Thickener Sludge Flow (mgd or cu m/day)

TSS - Total Suspended Solids (mg/l)

TSU - Total Sludge Units (ASU + CSU)

TXU - Total Excess Sludge Units To Waste (ESU + XSU)

WCR - Weight To Concentration Ratio (MLTSS / ATC)

WCRS - Weight To Concentration Ratio - Return Sludge (RSTSS / RSC)

V - Volume Of Aeration Tank (gal, cu ft, or cu m)

XFP - Excess Sludge Flow (as Percent of AFI)

XMF - Excess Mixed Liquor Sludge Flow To Waste (mgd or cu m/day)

XRF - Excess Return Sludge Flow To Waste (mgd or cu m/day)

XSC - Excess Sludge Concentration (% by Centrifuge)

XSF - Total Excess Sludge Flow To Waste (mgd or cu m/day)

XSU - Total Excess Sludge Units To Waste

NOTE: It is necessary, especially in Part IIIB, to use subscript notation to refer to particular bays within an aeration tank or to refer to flow values into a particular bay of an aeration tank. Several parameters, ADT, AFI, ATC, AV, AVG, TFL and V are combined with subscripts in Part IIIB. With these parameters, the reader need only remember that the number refers to the bay of the aeration tank. For example, ATC2 means the concentration of the mixed liquor, % by centrifuge, in the second bay of the aeration tank. AVG3 means the volume of the third bay expressed in gallons. TFLj means the total flow through the "j th" bay, and finally, TFLj-1 means the total flow through the bay preceding the "j th" bay.

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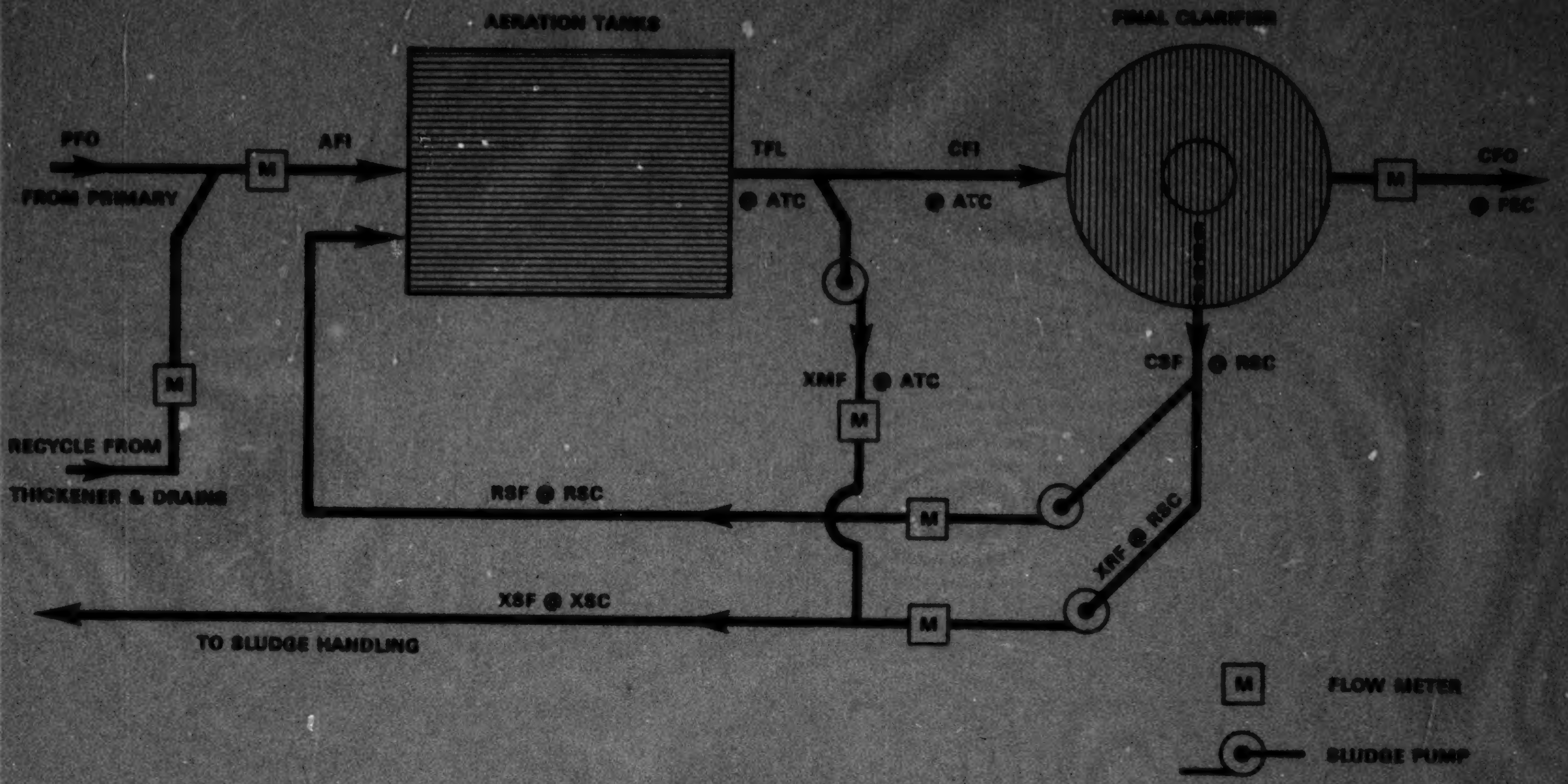
AERATION TANKS
FINAL CLARIFIER
PFO
FROM PRIMARY
M
AFI
RECYCLE FROM
THICKENER & DRAINS
TFL
@ ATC
CFI
@ ATC
CFO
@ PEC
XMF @ ATC
CSF @ RSC
RSF @ RSC
XRF @ RSC
XSF @ XSC
TO SLUDGE HANDLING
M FLOW METER
SLUDGE PUMP

TYPICAL CONVENTIONAL
ACTIVATED SLUDGE PLANT

EQUIVALENTS USED FOR ACTIVATED SLUDGE CALCULATIONS

ft x 0.3048 = m
inches x 2.540 = cm
m x 3.28083 = ft
m x 39.37 = in

sq ft x 0.0929 = sq m
sq m x 10.7639 = sq ft

cu ft x 28.3170 = liter
cu ft x 0.028317 = cu m
cu ft x 7.48052 = gal
cu m x 1000.0 = liter
cu m x 35.3145 = cu ft
cu m x 264.179 = gal

gal x 3.785 = liter
gal x 0.003785 = cu m
liter x 0.26417 = gal
mgd x 3785 = cu m/day
cu m/day x 0.000264 = mgd

gpd/sq ft x 0.0408 = cu m/day/sq m
cu m/day/sq m x 24.51 = gpd/sq ft

lb x 0.453592 = kg
lb x 453.592 = g
kg x 2.20462 = lb
kg x 1000.0 = g

lbs/1000 cu ft x 16.0 = g/cu m
g/cu m x 0.0625 = lbs/1000 cu ft

cu ft (H^2O) x 62.4 = lb (H^2O)
gal (H^2O) x 8.345 = lb (H^2O)
liter (H^2O) x 1.000 = kg (H^2O)

lb/day = mgd x mg/l x 8.345
kg/day = cu m/day x mg/l /1000

lb = English SLU x (WCR*/1198)
kg = Metric SLU x (WCR/10)

English SLU = Metric SLU x 264.2
Metric SLU = English SLU x 0.003785

*WCR = sludge weight (mg/l)/centrifuged concentration (%)

EPA-330/9-74-001e

NATIONAL WASTE TREATMENT CENTER - CINCINNATI

OPERATIONAL CONTROL PROCEDURES FOR THE ACTIVATED SLUDGE PROCESS

PART III-B

CALCULATION PROCEDURES

FOR
STEP-FEED PROCESS RESPONSES

by

Alfred W. West, P.E.

Director, National Waste Treatment Center
(formerly Waste Treatment Branch, National Field
Investigations Center - Cincinnati)

FEBRUARY 1975
(Revised Nov.,1975)

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF WATER PROGRAM OPERATIONS

FOREWORD

The National Waste Treatment Center (Cincinnati) is developing a series of pamphlets describing Operational Control Procedures for the Activated Sludge Process. This series, describing the "NWTC Procedures", will include Part I OBSERVATIONS, Part II CONTROL TESTS, Part III CALCULATION PROCEDURES, Part IV SLUDGE QUALITY, Part V PROCESS CONTROL and an APPENDIX. Each of these individual parts will be released for distribution as soon as it is completed, though not necessarily in numerical order. The original five-part series may then be expanded to include case histories and refined process evaluation and control techniques.

This pamphlet has been developed as a reference for Activated Sludge Plant Control lectures I have presented at training sessions, symposia, and workshops. It is based on my personal conclusions reached while directing the operation of dozens of different activated sludge plants. This pamphlet is not necessarily an expression of Environmental Protection Agency policy or requirements.

The mention of trade names or commercial products in this pamphlet is for illustrative purposes and does not constitute endorsement or recommendation for use by the Environmental Protection Agency.

Alfred W. West

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INTRODUCTION

An activated sludge plant that has been designed to permit operation in a plug-flow, step-feed, or contact-stabilization mode provides great control flexibility and can be operated many different ways. Calculations of step-feed process characteristics, however, are more complex than the previously illustrated calculations for aeration tanks operating in the plug-flow mode. Though few operators will perform all the step-feed calculations, all should be generally aware of the oxidation and purification pressure changes that occur when the process mode is shifted through various combinations of step loading.

The Summary, which probably is the most useful part of this section, illustrates the types of changes that occur when a plug-flow system is switched to various step-feed combinations.

Of nearly equal importance are the calculation procedures used to determine the sludge and waste detention times in a step-feed configuration. Then the additional process parameters unique to step-feed are shown. Finally, the rationale of the calculation procedures is included for those who may be interested in the derivations.

The intent of this pamphlet is not to describe specific step-feed locations that are most appropriate for all plant loading and sludge quality combinations. The illustrations and examples are intended to emphasize how the activated sludge process reacts to changes in wastewater feed-point locations. The Calculation Forms present an orderly procedure to determine, and at times predict, process response to various step-feed loadings. Other feed configurations could at times be more beneficial than those shown in the illustrations.

SUMMARY

Treatment plants at which operators can switch wastewater in-flow from one bay of an aeration tank to one or more other bays (step-feeding) have additional ways to meet the process demands of the activated sludge system. Recognition of the process demands that call for such control changes and knowledge of what happens when step-feeding is employed provide the foundation for successful operation of such plants. The curves on Figure 1 show how shifting wastewater in-flow locations exerts forces on mixed liquor *sludge oxidation* that are opposite to those exerted on *wastewater treatment.* Knowledge of these facts alone permits operators to shift step control in the proper direction to correct sludge or final effluent deficiencies and to restore best process balance.

SLUDGE OXIDATION PRESSURES

Oxidative pressures imposed on the activated sludge increase as the wastewater enters farther away from the head and closer to the exit end of the compartmented aeration tanks.

WASTEWATER TREATMENT PRESSURES

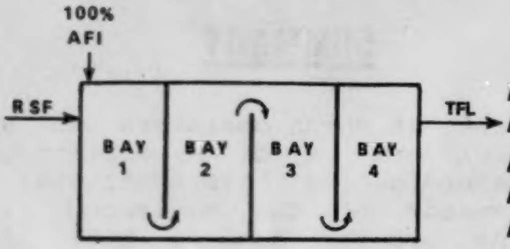
Purification pressures exerted on the wastewater decrease as it enters farther away from the head end and closer to the exit end of the aeration tanks.

DISCUSSION

Total aeration tank volumes and return sludge and waste water flows shown in Figure 2 are similar to those used in the calculation examples presented in Part III-A. The aeration tank characteristics used in this Summary example differ from those in Part III-A because the tank is divided into four equal step-feed bays, but the flows differ only slightly when the sludge wasting rate is set at zero.

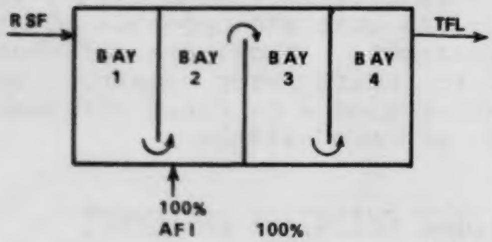
In addition to the process changes induced directly by switching step-feed inlet locations, the impact of such changes will be further governed by any variation in the sludge wasting rate.

PLUG FLOW
100% AFI
TO BAY 1.


100%
AFI
RSF
BAY 1
BAY 2
BAY 3
BAY 4
TFL

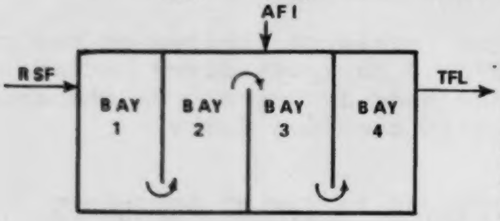
AGE = 6.0 days
ATC_m = 5.0 %
ASDT = 4.2 hours
AWDT = 4,2 hours
ATC x AWDT = 21.0

100% AFI
TO BAY 2


RSF
BAY 1
BAY 2
BAY 3
BAY 4
TFL
100%
AFI

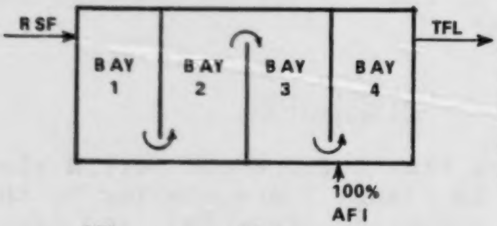
AGE = 8.2 days
ATC_m = 7.4 %
ASDT = 6.2 hours
AWDT = 3.1 hours
ATC x AWDT = 15.7

100% AFI
TO BAY 3


100%
AFI
RSF
BAY 1
BAY 2
BAY 3
BAY 4
TFL

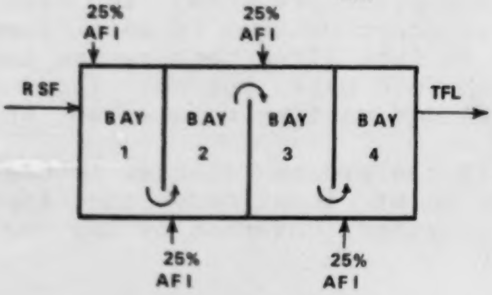
AGE = 10.4 days
ATC_m = 10.0 %
ASDT = 3.4 hours
AWDT = 2.1 hours
ATC x AWDT = 10.4

CONTACT STAB.
100% AFI
TO BAY 4


RSF
BAY 1
BAY 2
BAY 3
BAY 4
TFL
100%
AFI

AGE = 12.5 days
ATC_m = 12.5 %
ASDT = 10.5 hours
AWDT = 1.1 hours
ATC x AWDT = 5.2

STEP-FEED
25% AFI
TO EACH BAY


25%
AFI
25%
AFI
RSF
BAY 1
BAY 2
BAY 3
BAY 4
TFL
25%
AFI
25%
AFI

AGE = 7.8 days
ATC_m = 7.1 %
ASDT = 6.0 hours
AWDT = 3.3 hours
ATC x AWDT = 22.3

WASTEWATER FEED INLET LOCATIONS FOR FIGURE 1

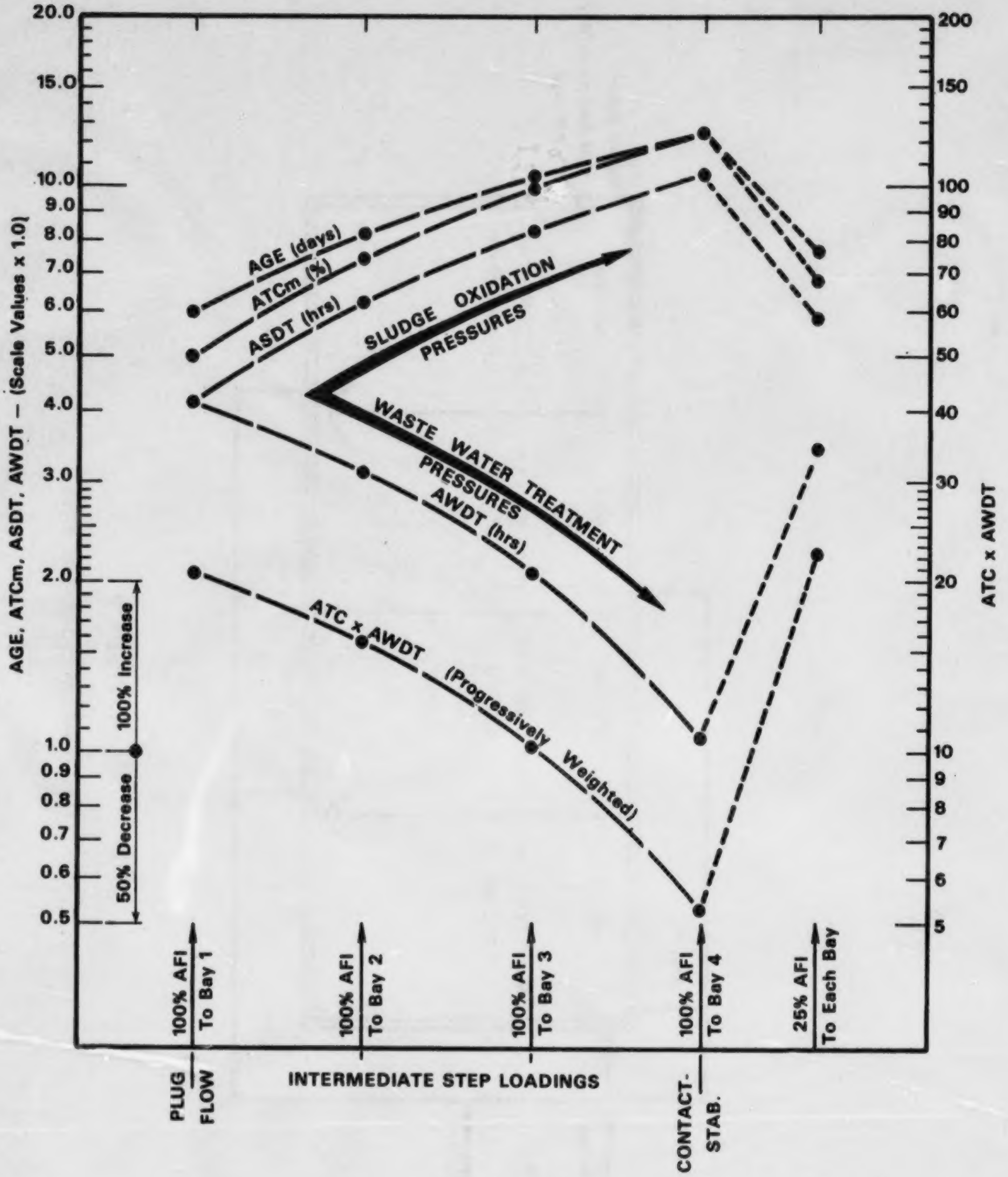


Figure 1

SLUDGE OXIDATION & WASTE TREATMENT PRESSURES

At Various Step-Aeration Loadings

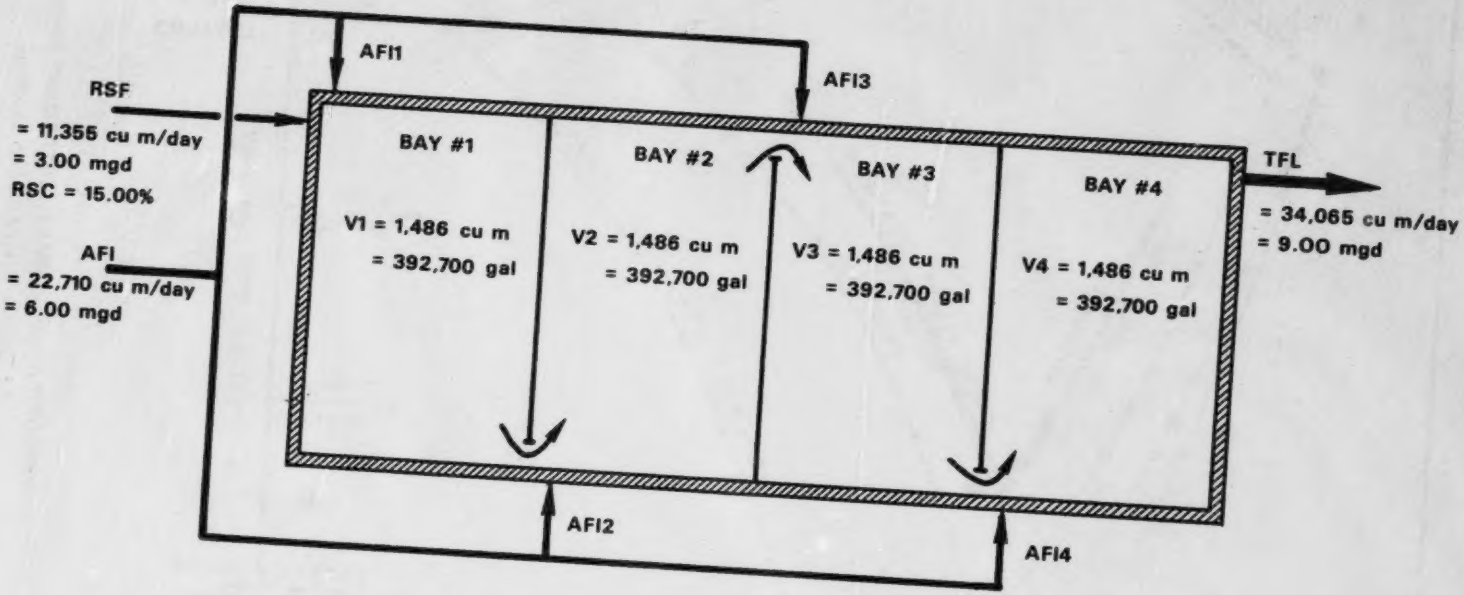

RSF
= 11,356 cu m/day
= 3.00 mgd
RSC = 15.00%
AFI
= 22,710 cu m/day
= 6.00 mgd
AFI1
AFI2
AFI3
AFI4
BAY #1
BAY #2
BAY #3
BAY #4
V1 = 1,486 cu m
= 392,700 gal
V2 = 1,486 cu m
= 392,700 gal
V3 = 1,486 cu m
= 392,700 gal
V4 = 1,486 cu m
= 392,700 gal
TFL
= 34,065 cu m/day
= 9.00 mgd

Figure 2

FOUR BAY STEP-AERATION TANK

EXAMPLE A

Sludge Wasting Rate Decreased

Normally increased sludge oxidation pressures can be maximized and normally decreased waste treatment pressures can be improved by a coordinated reduction in the sludge wasting rate when the step-feed in-flow location is shifted toward the bays nearer the aeration tank outlet end.

This is the case discussed in the Summary and illustrated in Figures 1 and 2. The reduced wasting rate, in effect, increases the number of sludge units in the system, eventually restores RSC to 15.0%, and increases sludge age. The mixed liquor concentration in the last bay (ATCn) would also be restored to 5.0% after a short-term sag in both RSC and ATCn. Obviously, aeration devices must be powerful enough to support the increased mixed liquor concentrations, and final clarifiers must provide the depth and surface area needed to permit proper compaction of the slower-settling, high-concentration sludge mass.

This coordinated control procedure, shifting step-feed toward the outlet end while simultaneously reducing sludge wasting, is usually appropriate to restore balance when the mixed liquor sludge settling rates have become too slow but still do not approach the almost negligible rates associated with true classic bulking. Such sludge quality degradation can be caused, for example, by a short-term organic overload that increases production of the new, underoxidized slow-settling component of the mixed liquor mass. The altered process requirements can then be met by moving the wastewater in-flow nearer the aeration tank outlet to increase oxidative pressures and, by decreasing the sludge wasting rate, to increase sludge age slightly.

EXAMPLE B

Sludge Wasting Rate Held Constant

Sludge oxidation pressures will be increased only nominally and waste treatment pressures will be reduced more sharply if the sludge wasting rate is held constant or increased after the in-flow location is shifted, as was done in Example A.

This phenomenon will be detailed in following sections where comparisons of other sludge and process responses to varied in-flow locations, wasting rates, and return sludge flow percentages are discussed.

Although not illustrated in Figure 1, the mixed liquor concentration of the outlet bay (ATCn), the number of sludge units returned to the aeration tanks (RSU), and the waste treatment pressure represented by RSU per 1000 gallons of wastewater or per pound of incoming BOD all remained constant throughout Example A but dropped in Example B when the step-feed location was shifted toward the outlet end.

Holding the sludge wasting rate constant, as discussed in Example B, will usually lower sludge blanket levels that have risen too high in hydraulically overloaded final clarifiers. Since identical quality mixed liquor sludges (same AGE, WCR, SSC60, etc.) settle more rapidly as their concentrations (ATC) are reduced, this particular response is governed mainly by the reduced ATCn.

CONCLUSIONS

The following conclusions are based on both fundamental theory and on the author's observations at step-feed plants that were operated according to his direction.

1. *Degraded sludge quality associated with decreasing settling and compaction rates can usually be improved by shifting the step-feed location toward the outlet end of the aeration tanks.*

In this case, sludge oxidation pressures can be maximized by shifting all the way to the last bay to approximate contact stabilization. The final effluent will be temporarily degraded, but restoring proper sludge quality will improve effluent quality to produce a long-term, beneficial effect on receiving waters. The step-feed location is then usually shifted back toward the plug-flow configuration after sludge quality has improved sufficiently.

2. *Final effluent quality can usually be improved by shifting the step-feed location toward the head end of the aeration tanks.*

In this case, the treatment pressures can be maximized by shifting all the way back to the first bay in the conventional plug-flow mode. This presupposes that the plant has adequate capacity and that thorough and complete mixing takes place in each bay.

BASIC CALCULATION PROCEDURES

DATA SOURCES AND TEXT ORGANIZATION

Calculation procedures used by the Waste Treatment Branch of the NFIC-C during technical support projects are described in Part III of the Operational Control Procedures for the Activated Sludge Process. The suggested types and frequency of observations and control tests have been described in Parts I and II.

Part III-A emphasizes calculation procedures for conventional activated sludge plants. This Part III-B utilizes the same text organization format and the same plant geometry. The difference between the two pamphlets is that this Part stresses the calculation procedures for the facility that has been provided with the step-feed capability. In addition to the calculation procedures, comparisons are made to the plug-flow parameters of Part III-A to emphasize those values which change as the process is shifted from the plug-flow to the step-feed mode.

Flow meter readings and control test results comprise the "Observed" data that are entered in the formulas to determine the "Wanted" information.

All calculations are performed in step-by-step fashion and in most cases tabular calculation forms are provided to illustrate the proper sequence of calculation steps to be used in obtaining intermediate and final results. All examples are expressed in separate metric unit and English unit sections to avoid confusion. A table of equivalents is printed inside the front cover. Figure 3 identifies the tank sizes, flow rates, and sludge concentrations used in the calculation examples. For convenience, each example is preceded by definitions of the symbols used in it. A complete list of all symbols and their definitions is included in the Appendix to this pamphlet series.

Though this Part requires numerical notation, the reader need only remember that the number refers to the bay of the aeration tank. For example, ATC2 means the concentration of the mixed liquor (% by centrifuge) in the second bay of the aeration tank. AVG3 means the volume of the third bay expressed in gallons. TFLj means the total flow through the "j th" bay, and finally, TFLj-1 means the total flow through the bay preceding the "j th" bay.

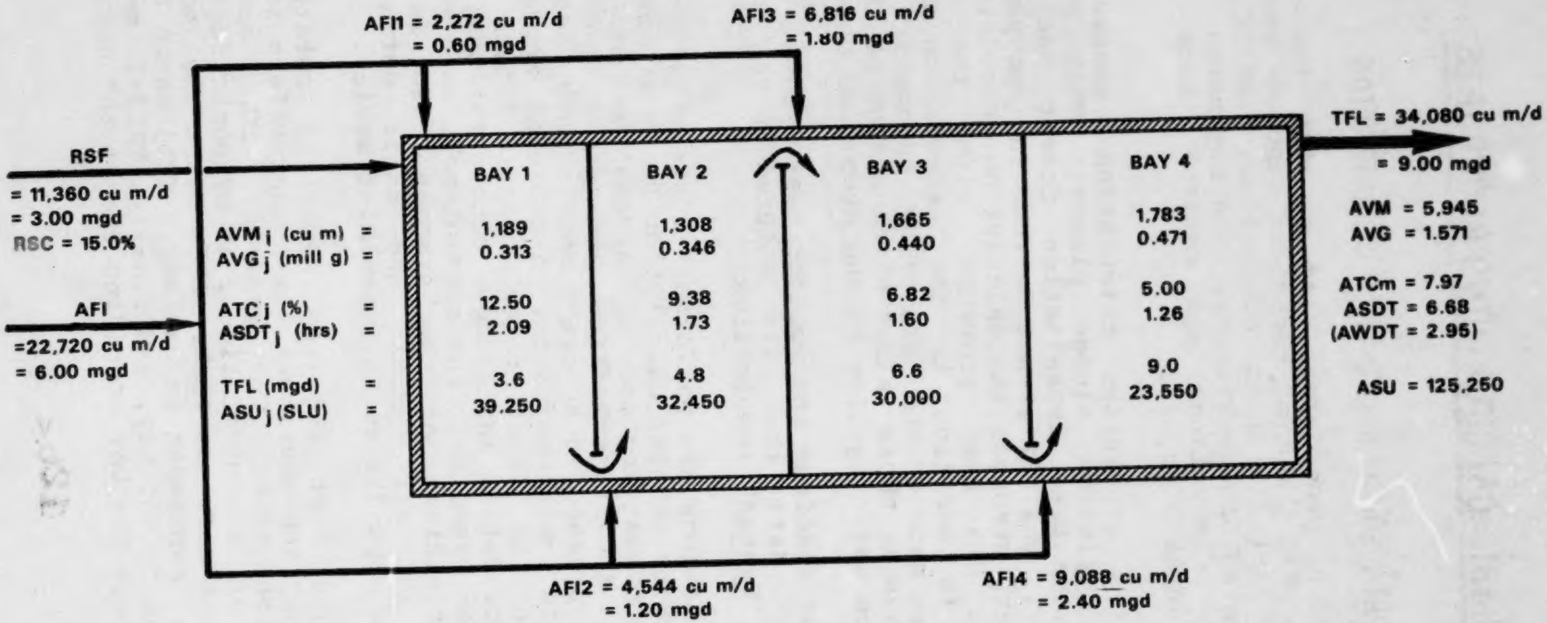

AFI1 = 2,272 cu m/d
= 0.60 mgd
AFI3 = 6,816 cu m/d
= 1.80 mgd
RSF
= 11,360 cu m/d
= 3.00 mgd
RSC = 15.0%
AFI
=22,720 cu m/d
= 6.00 mgd
AVM$_j$ (cu m) =
AVG$_j$ (mill g) =
ATC$_j$ (%) =
ASDT$_j$ (hrs) =
TFL (mgd) =
ASU$_j$ (SLU) =
BAY 1
1,189
0.313
12.50
2.09
3.6
39,250
BAY 2
1,308
0.346
9.38
1.73
4.8
32,450
BAY 3
1,665
0.440
6.82
1.60
6.6
30,000
BAY 4
1,783
0.471
5.00
1.26
9.0
23,550
TFL = 34,080 cu m/d
= 9.00 mgd
AVM = 5,945
AVG = 1.571
ATCm = 7.97
ASDT = 6.68
(AWDT = 2.95)
ASU = 125,250
AFI2 = 4,544 cu m/d
= 1.20 mgd
AFI4 = 9,088 cu m/d
= 2.40 mgd

Figure 3

AERATION TANK CHARACTERISTICS FOR THE CALCULATION EXAMPLE

USE OF CALCULATED RELATIONSHIPS

The Summary statements should help an operator determine what to do when faced with deteriorating sludge or effluent quality. They should help him start shifting wastewater feed location in the proper direction along the aeration tank flow path with greater assurance that he will, in fact, be performing a corrective control adjustment.

But most operators will also wish to know if they are shifting far enough and fast enough. Many will want to determine the actual sludge oxidation and wastewater treatment pressure changes that followed their process control adjustments. And some will wish to trim up their step-feed adjustments to achieve the best net result. To do this, the operator needs more numbers. Although the calculation of certain factors governing step-feed operation is more complex than that in plug-flow operations, it is not really too difficult if approached in an orderly manner. Such numbers can be determined quite easily and rapidly with the aid of a computer and fairly readily using a good desk calculator. Finally, though more time consuming, they can be determined by pencil-and-paper simple arithmetic.

The following tabular formats are geared to help an operator post observed data, record intermediate calculation results, and determine the process pressures and responses without a computer. They should also help the more fortunate few set up orderly computer programs.

If you have not performed step calculations before, don't let the tables and methodology scare you. The procedures are not nearly as formidable as they may appear at first glance, even though you may have to plod laboriously through your first few trials. After that the logic will become more apparent and the procedures more systematized. You may then wish to determine additional process characteristics that can provide you with an even greater insight into the reactions occurring throughout your process. Above all, these efforts should help you produce a better final effluent.

SYMBOLS AND DATA USED IN THE EXAMPLES

To calculate aeration tank characteristics for step-feed or contact stabilization, it is necessary to average the characteristics over the separate compartments of the aeration tanks and, because the compartments may not all be the same volume, a weighted average must be used.

SYMBOLS

ADT - Aeration Tank Detention Time (Hours)
AFI - Aeration Tank Wastewater Flow-In
ASDT - Aeration Tank Sludge Detention Time (Hours)
ASU - Aeration Tank Sludge Units
ATC - Aeration Tank Concentration (% by Centrifuge)
ATCm - Mean Aeration Tank Concentration
ATCn - Aeration Tank Concentration (Final Bay)
AV - Aeration Tank Volume
AVG - Aeration Tank Volume (Gallons)
AVM - Aeration Tank Volume (Cubic Meters)
AWDT - Aeration Tank Waste Detention Time (Hours)
BODi - Five-day Biochemical Oxygen Demand of the Wastewater Entering (In) the Aeration Tanks
BODo - Five-day Biochemical Oxygen Demand of the Final Clarifier Effluent (out)
RSC - Return Sludge Concentration (% by Centrifuge)
RSF - Return Sludge Flow
TFL - Total Flow to Aeration Tank

EXAMPLES

Metric Units	English Units
Observed:	**Observed:**
Bays = 4	Bays = 4
ATC1 = 12.50 %	ATC1 = 12.50 %
ATC2 = 9.38 %	ATC2 = 9.38 %
ATC3 = 6.82 %	ATC3 = 6.82 %
ATC4 = 5.00 %	ATC4 = 5.00 %
AVM1 = 1,189 cu m	AVG1 = 314,000 gal
AVM2 = 1,308	AVG2 = 346,000
AVM3 = 1,665	AVG3 = 440,000
AVM4 = 1,783	AVG4 = 471,000
AVM = 5,945 cu m	AVG = 1,571,000 gal
AFI1 = 2,272 cu m/d	AFI1 = 0.600 mgd
AFI2 = 4,544	AFI2 = 1.200
AFI3 = 6,816	AFI3 = 1.800
AFI4 = 9,088	AFI4 = 2.400
AFI = 22,720 cu m/d	AFI = 6.000 mgd
RSF = 11,360 cu m/d	RSF = 3.000 mgd
RSC = 15.0 %	RSC = 15.0 %

CALCULATION FORMS

FORM A

Calculation Form A is used to compute those step-feed parameters that must be determined differently from the calculation of plug-flow parameters that were illustrated in Part III-A. The step-feed parameters involved include ASU, ASDT, AWDT and ATCxAWDT. Once these specific values are determined, however, calculation of other aeration tank parameters and the use of these values to compute additional relationships follow the simpler methods of Part III-A.

Calculation Form A is used directly when the mixed liquor concentration (ATC) in each bay has been measured and the wastewater flow into each bay (AFI) and the return sludge flow (RSF) have been metered. The known and the observed values in the example are italicized (*0.314*, *12.50*, *3.0* etc.) for convenient reference. Intermediate calculated values are shown in regular type (3.925, 39,250 etc.) and the final results are shown in bold, large type (**125,240 = ASU, ASDT = 6.68** etc.).

Calculations are started by posting all observed values in columns 1, 2, 5, 6, 7, 8, 9 and 12. Intermediate values are then calculated, step by step, by following the instructions printed in each column. The instruction of "1x2" in column 3, for example, states that for the first bay (j=1), the intermediate "AVxATC" value is obtained by multiplying the *0.314* AVG in column 1 by the *12.50* ATC in column 2, i.e., *0.314* x *12.50* = 3.925 as posted in column 3.

According to the "5+6+7+8+9" instruction in column 10:

TFL = *3.00* + *0.60* + 0.00 + 0.00 + 0.00 = 3.60 for Bay 1
TFL = *3.00* + *0.60* + *1.20* + 0.00 + 0.00 = 4.80 for Bay 2
TFL = *3.00* + *0.60* + *1.20* + *1.80* + 0.00 = 6.60 for Bay 3
TFL = *3.00* + *0.60* + *1.20* + *1.80* + *2.40* = 9.00 for Bay 4

After all intermediate calculations have been performed, the desired process characteristic is determined by following the printed instructions at the bottom of the Table. The mean ATCxAWDT (shown below column 25), for example, is determined by dividing the total of the four column 25 values (121.930) by the total of four column 12 values (6.00), e.g., ATCxAWDT = 121.930/6.00 = 20.32

CALCULATION FORM A

To Determine ASU, ASDT, AWDT and ATCxAWDT

From Observed: ATC, RSF, and AFI

Bay No.	1	2	3	4	5
	Obs AVG (mil g)	Obs ATC (%)	AVx ATC	ASU (SLU)	Obs RSF (mgd)
			1x2	$(10)^4$x3	
j=1	*0.314*	*12.50*	3.925	39,250	*3.00*
j=2	*0.346*	*9.38*	3.244	32,440	*3.00*
j=3	*0.440*	*6.82*	3.000	30,000	*3.00*
j=4	*0.471*	*5.00*	2.355	23,550	*3.00*
TOTAL	1.571 = AVG			125,240 = ASU	

Bay No.	6	7	8	9	10	11
	Obs AFI1 (mgd)	Obs AFI2 (mgd)	Obs AFI3 (mgd)	Obs AFI4 (mgd)	TFL (mgd)	ASDTj (hr)
					5+6+7 +8+9	$\frac{(24)x1}{10}$
j=1	*0.60*	▨	▨	▨	3.60	2.09
j=2	*0.60*	*1.20*	▨	▨	4.80	1.73
j=3	*0.60*	*1.20*	*1.80*	▨	6.60	1.60
j=4	*0.60*	*1.20*	*1.80*	*2.40*	9.00	1.26
TOTAL					ASDT = 6.68	

Note: $(10)^4$ and (24) are conversion factors, not Col. Nos.

CALCULATION FORM A (CONTINUED)

Bay No.	12	13	14	15	16	17	18
	Obs AFIj (mgd)	ASDT1 (hr)	ASDT2 (hr)	ASDT3 (hr)	ASDT4 (hr)	SUM (hr)	PRO-DUCT
		From Column 11				13+14+ 15+16	12x17
j=1	*0.60*	2.09	1.73	1.60	1.26	6.68	4.008
j=2	*1.20*		1.73	1.60	1.26	4.59	5.508
j=3	*1.80*			1.60	1.26	2.86	5.148
j=4	*2.40*				1.26	1.26	3.024
TOTAL	6.00						17.688

Divide Col. 18 TOTAL by Col. 12 TOTAL

17.688/6.00 = AWDT = 2.95

Bay No.	19	20	21	22	23	24	25
	ATCjx ASDTj	ATC1x ASDT1	ATC2x ASDT2	ATC3x ASDT3	ATC4x ASDT4	SUM	PRO-DUCT
	2x11	From Column 19				20+21+ 22+23	12x24
j=1	26.125	26.125	16.219	10.909	6.300	59.553	35.732
j=2	16.219		16.219	10.909	6.300	33.428	40.114
j=3	10.909			10.909	6.300	17.209	30.976
j=4	6.300				6.300	6.300	15.120
TOTAL							121.930

Divide Col. 25 TOTAL by Col. 12 TOTAL

121.930/6.00 = ATCxAWDT = 20.32

TABLE A

SUMMARY OF CALCULATIONS

TEST RESULTS	METRIC UNITS	ENGLISH UNITS
AV1	1,190 cu m	0.314 mil g
AV2	1,310	0.345
AV3	1,670	0.440
AV4	1,780	0.471
AV	5,950 cu m	1.571 mil g
AFI1	2,270 cu m/day	0.60 mgd
AFI2	4,540	1.20
AFI3	6,810	1.80
AFI4	9,080	2.40
AFI	22,710 cu m/day	6.00 mgd
RSF	11,360 cu m/day	3.00 mgd
BODi	160 mg/l	160 mg/l
BODo	10 mg/l	10 mg/l
MLVSS	3,000 mg/l	3,000 mg/l
RSTSS	12,000 mg/l	12,000 mg/l
ATC1	12.50 %	12.50 %
ATC2	9.38 %	9.38 %
ATC3	6.82 %	6.82 %
ATC4	5.00 %	5.00 %
ATCm	7.97 %	7.97 %
ASU1	149 SLU	39,250 SLU
ASU2	123 SLU	32,440 SLU
ASU3	114 SLU	30,000 SLU
ASU4	89 SLU	23,550 SLU
ASU	474 SLU	125,240 SLU

TABLE A (CONTINUED)

RESULTS OF INTERMEDIATE CALCULATIONS

	METRIC UNITS		ENGLISH UNITS	
BODi	3,630	kg/day	8,010	lb/day
MLVSS	17,840	kg	39,325	lb
RSTSS	136,270	kg/day	300,420	lb/day
ASDT	6.68	hr	6.68	hr
AWDT	2.95	hr	2.95	hr
RFP	50.00	%	50.00	%
RSC	15.00	%	15.00	%
RSU	1,700	SLU/day	450,000	SLU/day

AERATION TANK LOADINGS

BODi/AV	610	g/cu m	38.14	lb/1000cu ft
BODi/ASU	7,660	kg/1000ASU	63.96	lb/1000ASU
BODi/MLVSS (F/M)	0.20	kg/kg	0.20	lb/lb

PURIFICATION PRESSURES

ATCxAWDT	20.32		20.32	
ATCxAWDT/1000mg/l BODi	127		127	
RSU/1000AFI	75	RSU/1000cu m	75	RSU/1000gal
RSU/BODi	0.47	RSU/kg	56	RSU/lb
RSTSS/BODi	38	kg/kg	38	lb/lb

Explanatory Note: Some of the time-concentration dependent parameters in step-feed (for example, the ATCxAWDT factor described above) are based on the accumulated sums of products of factors for each specific bay of the aeration tank. As such, the weighted mean answers cannot be determined by the simple division of some of the previously calculated mean values. This fact need not be alarming because the instructions printed on the Calculation Forms take care of these special requirements.

The following explanation will help clarify the values that might be obtained from different calculation procedures.

The calculation procedure to determine ATCxAWDT for step-feed cannot be simplified by multiplying ATCm of 7.97 % (Table A) by the AWDT of 2.95 hours (Form A), 7.97 x 2.95 = 23.51, which does not equal the 20.32 ATCxAWDT oxidation pressure shown in Form A.

The reason for this becomes more apparent from the following more familiar example calculation of the average number of pounds of BOD5 entering a plant during a 3-day interval.

	Flow(mgd)	x	BOD5(mg/l)	x 8.345 =	lb of BOD5/day
Day 1	2.4	x	152	x 8.345 =	3,044
Day 2	1.5	x	140	x 8.345 =	1,752
Day 3	3.5	x	250	x 8.345 =	7,301
Sum	7.4		542		12,097
Avg.	2.467		180.67		4,032

But the BOD5 calculated from the average Flow and BOD5 (2.467 x 180.67 x 8.345 = 3,713) does not equal the 4,032 average of the three previously calculated BOD values.

AERATION TANK WASTEWATER FLOW-IN - AFI

Calculation Form A can be used directly to determine essential process relationships if flow rates (especially AFI1, AFI2, etc.) have been metered and if mixed liquor and return sludge concentrations (especially ATC1, ATC2, etc.) have been determined. In all too many plants, however, individual flow rates to each aeration tank bay cannot be measured. In such cases, the AFI values needed for use in Calculation Form A can be calculated from the measured RSF, RSC, and ATC values. Calculation Form B can be used to determine these AFI values.

CALCULATION FORM B

To Determine AFI

From Observed: RSF, RSC, and ATC

	1	2	3	4	5	6
Bay No.	Obs ATC j-1 (%)	Obs ATC j (%)	Dif (%)	TFL j-1 (mgd)	AFI j (mgd)	TFL j (mgd)
	From 2		1-2	From 6	$\frac{3x4}{2}$	4+5
j=1	*15.00	12.50	2.50	**3.00	0.60	3.60
j=2	12.50	9.38	3.12	3.60	1.20	4.80
j=3	9.38	6.82	2.56	4.80	1.80	6.60
j=4	6.82	5.00	1.82	6.60	2.40	9.00
TOTAL	AFI1 + AFI2 + AFI3 + AFI4 = AFI = 6.00					

* ATC @ (j-1) for Bay 1 = RSC

** TFL @ (j-1) for Bay 1 = RSF

The step-by-step calculation procedures in Form B are self-explanatory. As emphasized in Calculation Form B, the measured RSC is the "Observed ATC" for Bay j-1, and the metered RSF is the "Observed TFL" for Bay j-1. It is essential that all calculations for the first bay be completed before starting calculations for the second bay. As emphasized by the arrows on the form, the calculated TFL through Bay 1 (3.60) must be posted in the "TFLj-1" column in line "j=2" for use in calculating the AFI to the second bay. Calculations can then proceed from bay to bay until all AFI values are determined for use in Calculation Form A.

DISCUSSION OF EFFECTS OF SWITCHING TO VARIOUS STEP-FEED CONFIGURATIONS

Use of the calculation procedures to estimate the changes that could logically occur if the operational mode were changed all the way from plug-flow (all wastewater entering Bay #1) to contact stabilization (all wastewater entering Bay #4) is discussed and illustrated in this section.

Let's assume that a plant is operating in the plug-flow mode, sludge quality has been deteriorating for a week or more. The one-hour settled sludge concentration (SSC60), for example, has finally fallen from 15.0% to a dangerously low level of 6.0%. Let's further assume that the operator has been increasing return sludge flow percentages according to the calculated demands, but that he has finally reached the maximum capacity of his return sludge pumps at a flow rate equal to 100% of the incoming wastewater flow. Then let's finally assume that he has been unable to improve sludge quality by concurrent aeration intensity and sludge wasting control efforts. Such occurrences are not uncommon at plants suffering from either temporary or sustained overloads.

In cases like this, final effluent quality frequently remains excellent as long as the final clarifier sludge blanket formed by the slowly settling mixed liquor sludge is not forced up and out over the effluent weirs. It is, therefore, imperative that the operator modify control procedures before the decreasing sludge settling rates induce classic sludge bulking with the accompanying drastic deterioration of final effluent quality. Switching from plug-flow to step aeration would increase sludge oxidation pressures and most probably improve mixed liquor settling and concentration rates. Although final effluent quality will probably sag somewhat because of the reduction in the wastewater treatment pressures, such a sag will not nearly approach that which might otherwise occur if the present trend were permitted to continue right on to sludge bulking.

At this time, or preferably before the SSC60 had fallen to 6%, the operator could calculate the wastewater and sludge detention times that would result from step-feed configurations and then change into the mode he believes most appropriate. Shortly thereafter he should check the actual effect of the switchover by observing the changes reflected in the results of his operational control tests and utilizing tabular Forms A and B to calculate process parameters (ATCxAWDT, etc). Ultimately, he would modify the percentages of wastewater flow into the various aeration tank bays to best meet the actual plant loading and sludge quality requirements.

The operator will obviously measure flow rates and perform the normal operational control tests during and after the switch from plug-flow to contact stabilization. He should be able to observe distinctive changes in sludge quality within 3 to 7 days after the switchover. By this time better sludge quality, as indicated by increasing SSC60 values, can be expected. He should then be able to continue reduced sludge wasting rates to further increase ATC, RSC, sludge age, upgrade sludge quality, and improve process performance.

The object of this mode switch and these process control adjustments has been to improve sludge quality and force the SSC60 value upward. When this objective is reached or approached, the operator will then be primarily concerned with final effluent quality. He will want to maximize treatment pressures by shifting the step-feed loading back toward the plug-flow configuration. Now that the danger of sludge bulking has been removed, he can, for example, readjust the wastewater distribution to send approximately one-third of the waste flow to Bay 1 and continue routing two-thirds to Bay 4. As conditions improve, he can then decide to shift the two-thirds of the waste loading from Bay 4 to Bay 3 to further increase purification pressures. If all goes well, he should continue backing up in this manner until he can once again route all wastes to Bay 1, restore the process to plug-flow, and maximize the waste treatment pressures.

There are dozens of step-feed configurations that can be used to meet process demands. As discussed in the Summary Section, *shifting toward contact stabilization will increase sludge oxidation pressures and shifting toward plug-flow will increase wastewater purification pressures.*

TABLE B

Comparison Between Plug Flow & Contact Stabilization
@AFI=6.00 mgd, RSF=6.00 mgd, SSC60=6.0%,WCR=800, MLVSS=75%

TEST RESULTS (Measured or Calculated Values)					
	PLUG FLOW	CONTACT STABILIZATION			
		@ CONSTANT TSU		@ CONSTANT RSC	
			% *		% *
AVG (mil gal)	1.5708	1.5708	100	1.5708	100
AVG-Contact Tk	1.5708	0.3927	25	0.3927	25
AFI1 (mgd)	6.000	0	-	0	-
AFI2 (mgd)	0	0	-	0	-
AFI3 (mgd)	0	0	-	0	-
AFI4 (mgd)	0	6.000	-	6.000	-
AFI-Total (mgd)	6.000	6.000	100	6.000	100
RSF (mgd)	6.000	6.000	100	6.000	100
ATC1 (%)	3.0	4.0	133	6.0	200
ATC2 (%)	3.0	4.0	133	6.0	200
ATC3 (%)	3.0	4.0	133	6.0	200
ATC4 (%)	3.0	2.0	67	3.0	100
ATCm (%)	3.0	3.5	117	5.25	175
RSC (%)	6.0	4.0	67	6.0	100
RSU/Day	360,000	240,000	67	360,000	100
RSTSS (mg/l)	4,800	3,200	67	4,800	100
RSTSS (lb/day)	240,300	160,200	67	240,300	100
MLVSS (mg/l)	1,800	1,200	67	1,800	100
MLVSS (lb/day)	23,600	3,930	17	5,900	25
BODi (mg/l)	160	160	100	160	100
BODi (lb/day)	8,010	8,010	100	8,010	100
BODo (mg/l)	10	10	100	10	100

* Percent of Plug-Flow Value

	PLUG FLOW	CONTACT STABILIZATION			
		@ CONSTANT TSU		@ CONSTANT RSC	
			% *		% *
ASU-Total	47,100	54,700	116	82,500	175
CSU-Total	22,500	14,900	67	22,500	100
TSU-Total	69,600	69,600	100	105,000	150
ASU-Contact	47,100	7,850	17	11,780	25
AERATION TANK LOADINGS					
BODi/1000AVF	38	152	400	152	400
BODi/ 1000ASU	170	1,020	600	680	400
BODi/MLVSS (F/M)	0.34	2.04	600	1.36	400
SLUDGE OXIDATION PRESSURES					
ASDT (hrs)	3.14	5.5	175	5.5	175
CSDT (hrs)	1.50	1.5	100	1.5	100
SAH (hrs/day)	16.2	18.8	116	18.8	116
SAP	0.677	0.786	116	0.786	116
AGE (Days)	6.0	6.0	100	9.0	150
AAG (Days)	4.06	4.71	116	7.1	175
WASTEWATER PURIFICATION PRESSURES					
AWDT (hrs)	3.14	0.79	25	0.79	25
ATCxAWDT	9.42	1.56	17	2.36	25
ATCxAWDT/ 1000BODi	59.0	9.8	17	14.7	25
RSU/1000AFI	60.0	40.0	67	60.0	100
RSU/1b BODi	45.0	30.0	67	45.0	100
RSTSS/1b BODi	30.0	20.0	67	30.0	100

* Percent of Plug-Flow Value

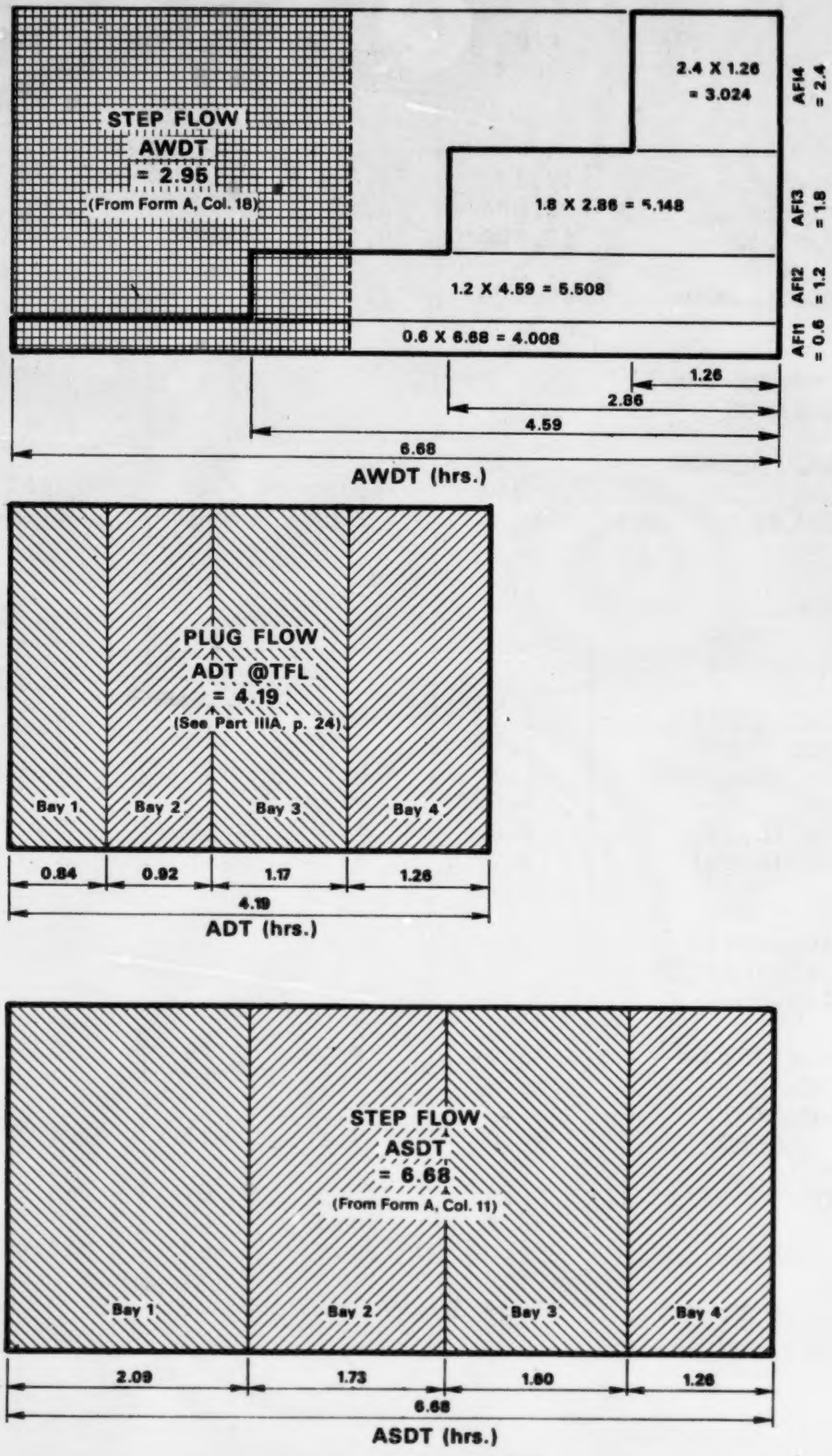

STEP FLOW
AWDT
= 2.95
(From Form A, Col. 18)
2.4 X 1.26
= 3.024
1.8 X 2.86 = 5.148
1.2 X 4.59 = 5.508
0.6 X 6.68 = 4.008
AFI4
= 2.4
AFI3
= 1.8
AFI2
= 1.2
AFI1
= 0.6
1.26
2.86
4.59
6.68
AWDT (hrs.)
PLUG FLOW
ADT @TFL
= 4.19
(See Part IIIA, p. 24)
Bay 1
Bay 2
Bay 3
Bay 4
0.84
0.92
1.17
1.26
4.19
ADT (hrs.)
STEP FLOW
ASDT
= 6.68
(From Form A, Col. 11)
Bay 1
Bay 2
Bay 3
Bay 4
2.09
1.73
1.60
1.26
6.68
ASDT (hrs.)

Figure 4
AERATION TANK DETENTION TIME

RATIONALE OF PROCEDURE DEVELOPMENT

The following diagrams were developed for those interested in reviewing the rationale used in developing the step-feed calculation procedures.

AWDT, ADT, & ASDT

The three shaded areas, representing detention times in Figure 4, reveal at a glance the extent to which sludge and wastewater aeration tank detention times are changed when the process mode is switched from plug-flow to step-feed. ADT, which is the same for both sludge and wastewater at plug-flow, is indicated by the size of the shaded middle sketch. The relative size of the shaded area of the upper sketch shows that the time wastewater is subjected to aeration (AWDT) was reduced to 70% of the plug-flow value after the mode was switched to step-feed. The relative size of the shaded area of the lower sketch shows that the time that sludge was subjected to aeration (ASDT) was increased to 160% of the former plug-flow value.

The ADT for plug-flow, illustrated in the middle sketch, is the sum of the time that the combined return sludge and wastewater (TFL) remained in each of the four bays.

The ASDT for step-feed, which is the time that sludge remains under aeration, (bottom sketch) is also the sum of the time that the combined return sludge and wastewater remained in each of the four bays. But in this case only a fraction of the wastewater flow was directed into each of the Bays. This reduced the total flow (TFL) through each of the first three bays (Column 10, Form A) and therefore increased the detention time in each of these bays (Column 11, Form A). Switching from plug-flow to step-feed increases the time that sludge is subjected to aeration.

Wastewater detention time (AWDT in the upper sketch) is calculated somewhat differently. The 0.6 mgd portion of the wastewater introduced to Bay 1 flows through all four bays and is therefore subjected to aeration for 6.68 hours. The product of this portion of the flow multiplied by its aeration detention time (0.6 x 6.68 = 4.008) is illustrated by the size of the bottom rectangle in the upper sketch.

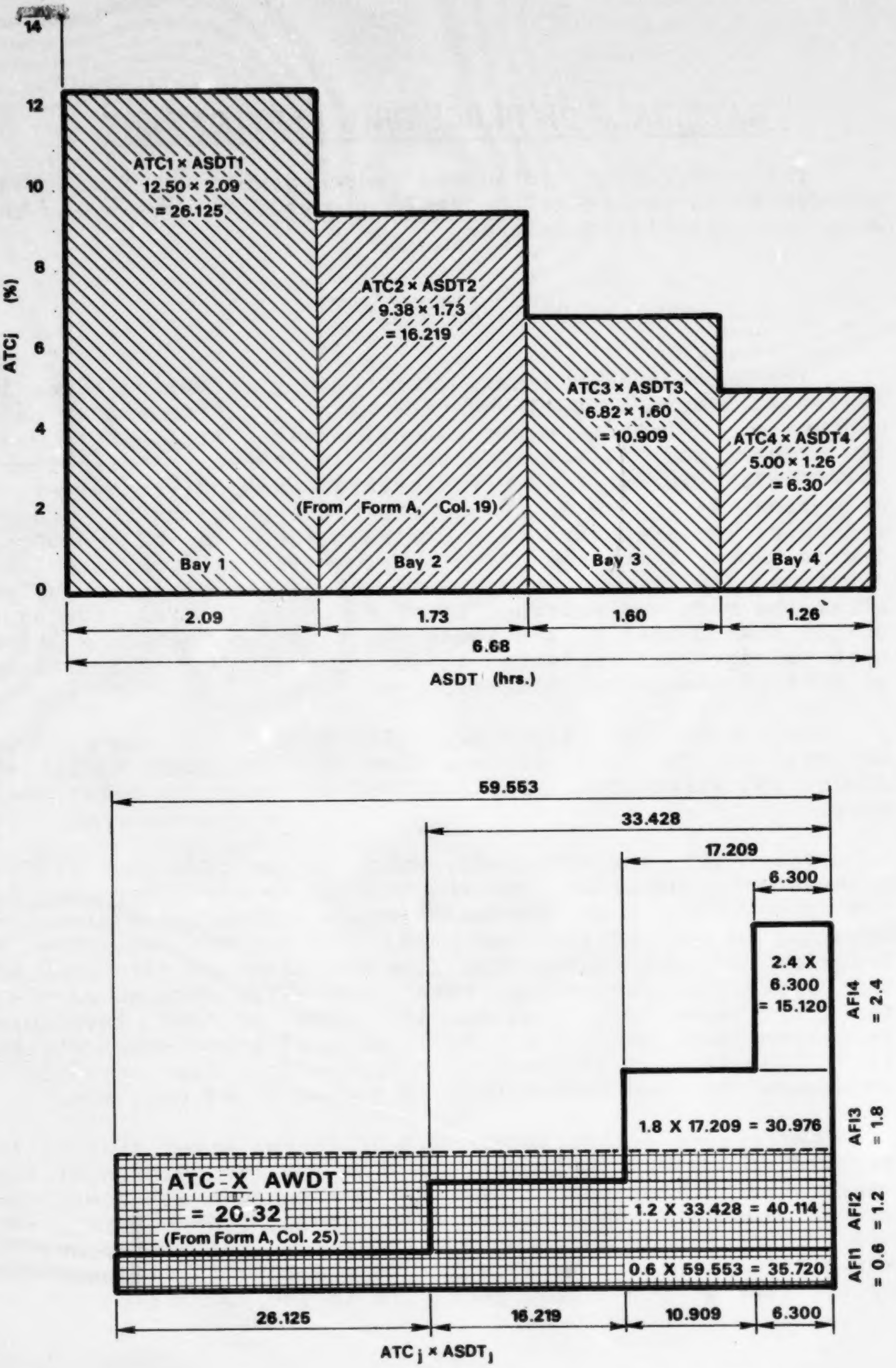


Figure 5

ATC × AWDT from ATC & ASDT

The 1.20 mgd portion of wastewater introduced into Bay 2, however, flows through only the last three bays and is subjected to aeration for only 4.59 hours. This product (1.2 x 4.59 = 5.508) is illustrated by the size of the second lower rectangle in the upper sketch.

Similarly, the portions of wastewater flow introduced into Bays 3 and 4 are subjected to even less aeration.

The shaded area of the upper sketch is equal to the sum of the areas of the four separate horizontal rectangles. The weighted mean wastewater detention time (AWDT) is therefore equal to the sum of the products of the individual flow portions times their respective aeration detention times divided by the wastewater flow (AFI). (17.688 from Column 18, Form A, divided by 6.0 from Column 12, Form A = 2.95 = AWDT)

ATC x AWDT

Calculation of the ATCxAWDT factor for step-feed is also based on a progressively weighted mean value determined somewhat similar to the previously described AWDT.

Wastewater flowing through each aeration tank bay is subjected to the ATCj x ASDTj in each bay (upper sketch and Column 19, Form A).

But, here again, only the 0.6 mgd portion of the wastewater that enters Bay 1 is subjected to the sum of the ATCj x ASDTj pressures in all four bays. This value (0.6 x 59.553 = 35.72) is represented by the lower rectangle in the bottom sketch.

The 1.2 mgd portion of the wastewater that enters Bay 2 is subjected to the sum of the ATCj x ASDTj pressures in the last three bays, etc. And so on.

The shaded area of the lower sketch in Figure 5 is equal to the sum of the areas of the four horizontal rectangles. The weighted mean ATC x AWDT for the entire cycle is equal to the sum of AFIj multiplied by the accumulated sum of ATCj x ASDTj; all are divided by the total AFI entering the aeration tank. (121.930 from Column 25, Form A, divided by 6.0 from Column 17, Form A = 20.32 = ATCxAWDT)

MEAN AERATION TANK CONCENTRATION - ATC$_M$

Since, in step-feed, the ATC will decrease from the first to the last compartment, a weighted mean ATC replaces the plug-flow ATC. To determine the weighted mean ATC, (ATCm), multiply each compartment's ATC by the compartment's volume, add these terms together, and divide by the total aeration tank volume. Thus, for a four compartment aeration tank with the individual compartment ATC's measured:

$$\mathrm{ATC_M = (ATC1xAV1 + ATC2xAV2 + ATC3xAV3 + ATC4xAV4)\ /\ AV}$$

Figure 6 graphically displays this calculation procedure. The area outlined with the heavy line is the sum of ATC1xAV1 + ATC2xAV2 + ATC3xAV3 + ATC4xAV4. This area must and does equal the shaded area. ATCm is then calculated by dividing the area by the total aeration tank volume, AV.

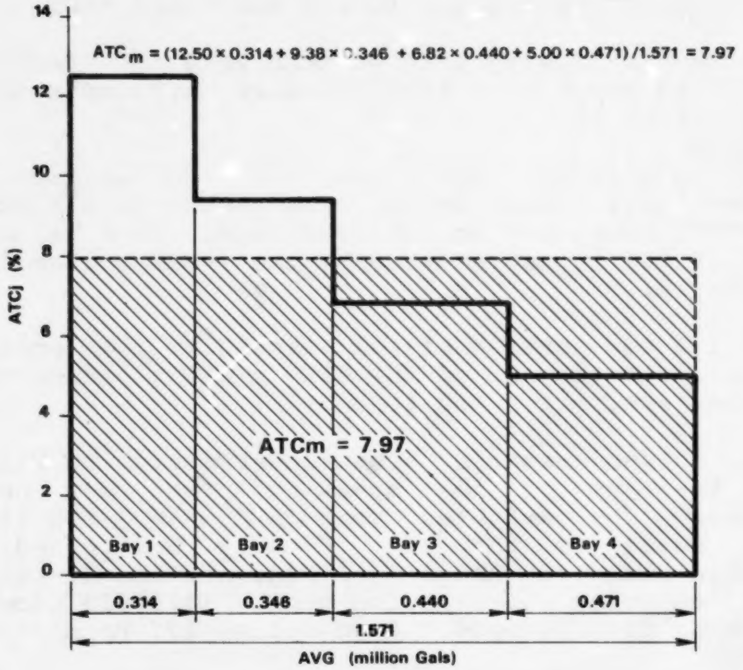


Figure 6

FORMULAS FOR STEP-FEED CALCULATIONS

The formulas used to determine the various step-feed relationships are provided for those who may wish to set up their own special calculation procedures or program a computer to do the work. All equations are set up on the basis of a four-bay aeration system.

FORMULAS USED IN CALCULATION FORM A

The following formulas show the equations for the process evaluation factors shown in Form A:

$$ASDT_j = \frac{24 \times AVG_j}{TFL_j}$$

$$ASDT = \sum_{j=1}^{n} ASDT_j$$

$$AWDT = \frac{\sum_{i=1}^{n} AFI_i \sum_{j=i}^{n} ASDT_j}{AFI}$$

$$ATC \times AWDT = \frac{\sum_{i=1}^{n} AFI_i \sum_{j=i}^{n} ASDT_j \times ATC_j}{AFI}$$

$$ASU = 10{,}000 \times AV \times ATC_m$$

FORMULAS USED IN CALCULATION FORM B

If the AFI to each bay is unmetered and unknown, each AFIj or percent of AFI can be calculated from AFI, RSF, RSC, and ATCj from the following:

$$AFI1 = (RSF)(RSC-ATC1) / ATC1$$

$$AFI2 = (RSF+AFI1)(ATC1-ATC2) / ATC2$$

$$AFI3 = (RSF+AFI1+AFI2)(ATC2-ATC3) / ATC3$$

$$AFI4 = (RSF+AFI1+AFI2+AFI3)(ATC3-ATC4) / ATC4$$

ATCM & ATCN

The following two equations are used to calculate the weighted mean aeration tank concentration (ATCm) and if it should be required the concentration of the last bay in the aeration tank (ATCn):

$$ATC_m = \sum_{j=1}^{n} \frac{ATC_j \times V_j}{AV}$$

The last compartment ATC is given by:

$$ATC_N = RSF \times RSC / (RSF+AFI) = RSF \times RSC / TFL$$

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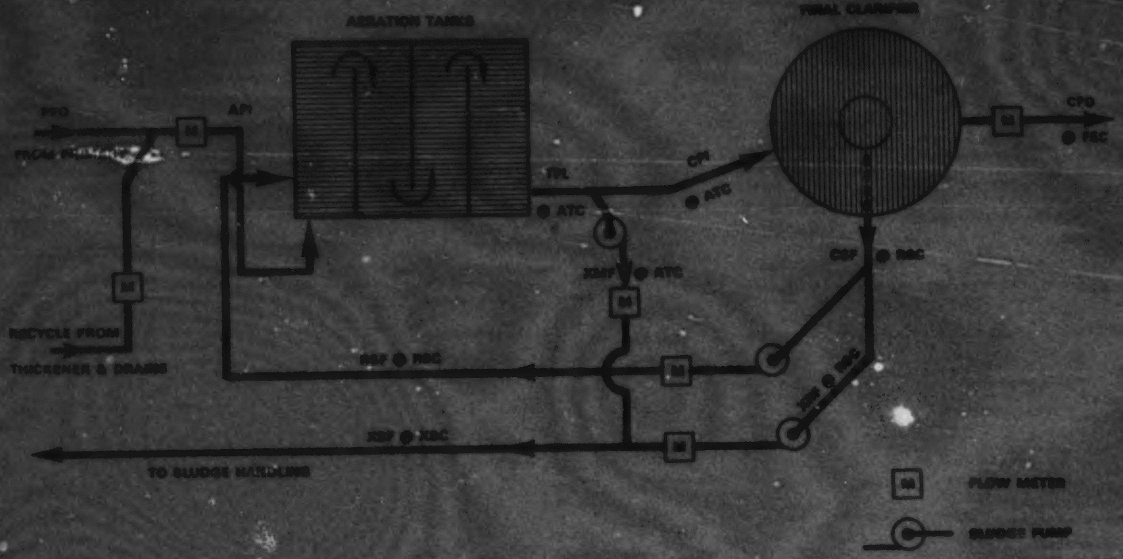
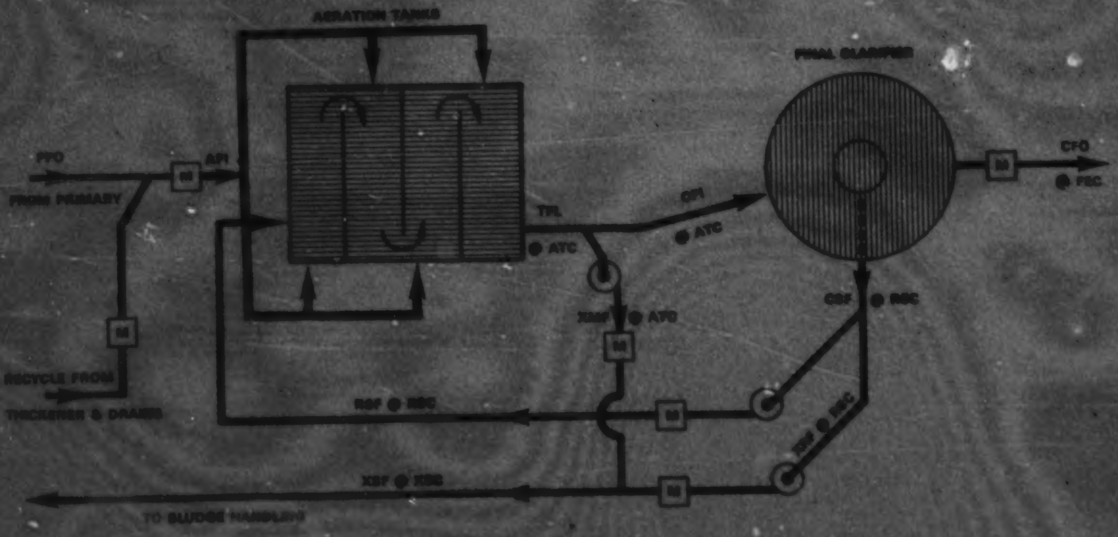

AERATION TANKS
FINAL CLARIFIER
PFO
FROM PRIMARY
API
M
TFL
● ATC
CFI
● ATC
CFO
● FSC
CSF ● RSC
XMF ● ATC
RECYCLE FROM
THICKENER & DRAINS
RSF ● RSC
XSF ● RSC
XSF ● XSC
TO SLUDGE HANDLING
M
FLOW METER
SLUDGE PUMP

TYPICAL PLUG FLOW ACTIVATED SLUDGE PLANT


AERATION TANKS
FINAL CLARIFIER
PFO
FROM PRIMARY
API
M
TFL
● ATC
CFI
● ATC
CFO
● FSC
CSF ● RSC
XMF ● ATC
RECYCLE FROM
THICKENER & DRAINS
RSF ● RSC
XSF ● RSC
XSF ● XSC
TO SLUDGE HANDLING

TYPICAL STEP-FEED ACTIVATED SLUDGE PLANT

NATIONAL WASTE TREATMENT CENTER
(Formerly National Field Investigations Center)

OPERATIONAL CONTROL PROCEDURES
FOR THE
ACTIVATED SLUDGE PROCESS

ADDENDUM NO. 1

To The February 1975

PART III-B

CALCULATION PROCEDURES
FOR
STEP-FEED PROCESS RESPONSES

by

Alfred W. West, P.E.
Director, National Waste Treatment Center

AUGUST 1975

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER AND HAZARDOUS MATERIALS

FOREWORD

The National Waste Treatment Center (Cincinnati) is developing a series of pamphlets describing Operational Control Procedures for the Activated Sludge Process. The series will include Part I OBSERVATIONS, Part II CONTROL TESTS, Part III CALCULATION PROCEDURES, Part IV SLUDGE QUALITY, Part V PROCESS CONTROL and an APPENDIX. Parts I and II were originally printed as separate pamphlets dated April 1973. The May 1974 printing combined the two Parts which includes some revisions concerning use of the centrifuge and dilution settlometer tests. Each part will be released for distribution as soon as it is completed, though not necessarily in numerical order. The original five-part series may then be expanded to include case histories and refined process evaluation and control techniques.

This pamphlet has been developed as a reference for Activated Sludge Plant Control lectures I have presented at training sessions, symposia, and workshops. It is based on my personal conclusions reached while directing the operation of dozens of activated sludge plants. This pamphlet is not necessarily an expression of Environmental Protection Agency (EPA) policy or requirements.

The mention of trade names or commercial products in this pamphlet is for illustrative purposes and does not constitute endorsement or recommendation for use by the EPA.

Alfred W. West

CALCULATION FORM A

Calculation Form A on pages 12 & 13 of the February 1975 PART III-B was set up in a step-by-step format to correspond directly to the explanatory Rationale of Procedure Development on pages 22 through 26.

Once the governing principles and assumptions are understood, however, some of the steps can be combined for more direct, and somewhat simpler, calculation of the Process Characteristics. The following Simplified Calculation Form Example, that does not require AFIj input, can be used instead of the original FORM A.

SIMPLIFIED CALCULATION FORM EXAMPLE

Direct Measurements

No. of Bays = 4
AFI = 6.0 mgd
AVG = 1.571 mgd
RSF = 3.0 mgd
RSC = 15.0%

Intermediate Summations

Bay No.	1	2	3	4
	AV (mil g)	ATC (%)	AV x ATC	AV x ATC
	Obs.	Obs.	1 x 2	2 x 3
j=1	0.314	12.50	3.925	49.063
j=2	0.346	9.38	3.245	30.443
j=3	0.440	6.82	3.001	20.465
j=4	0.471	5.00	2.355	11.775
TOTAL	1.571		12.526	111.746

PROCESS CHARACTERISTIC CALCULATIONS

To use the following Process Characteristic equations, the preceding Intermediate Summations Table must first be completed. The column TOTALS are then substituted into the equations as indicated.

ATCm = Column 3 / Column 1

= 12.526 / 1.571

= 7.97

ASDT = 24 x AVG x ATCm / RSF x RSC

= 24 x 1.571 x 7.97 / 3.0 x 15.0

= 6.68

AWDT = 24 x AVG x (RSC - ATCm) / AFI x RSC

= 24 x 1.571 x (15.0 - 7.97) / 6.0 x 15.0

= 2.95

$$\text{ATCxAWDT} = 24 \times \text{AVG} \left[\text{ATCm} - (\text{Col. 4} / \text{RSC} \times \text{AVG}) \right] / \text{AFI}$$

$$= 24 \times 1.571 \left[7.97 - (111.746 / 15.0 \times 1.571) \right] / 6.0$$

= 20.28

ASU = 10,000 x AVG x ATCm

= 10,000 x 1.571 x 7.97

= 125,240

FORMULAS USED IN CALCULATION OF FORM B

The first group of four formulas on page 28 of the February 1975 Part III-B must be used in proper sequence. That is, AFI1 must be calculated first for use in the AFI2 formula, and AFI1 and AFI2 are needed to calculate AFI3, etc.

The following two formulas permit direct AFIj and TFLj calculations for any bay.

$$\mathbf{AFI_j = RSF \times RSC \left(\frac{1.0}{ATC_j} - \frac{1.0}{ATC_{j-1}} \right)}$$

(where ATCj-1 = RSC for Bay 1)

$$\mathbf{TFL_j = \frac{RSF \times RSC}{ATC_j}}$$

REQUEST FOR NFIC-C AUDIOVISUAL INSTRUCTION UNITS

The Audiovisual request form on page 29 erroneously implied that the tapes and slides were available at no charge.

Actually; the catalogs are free, the tapes and slides may be borrowed, but the cost of reproduction is charged for permanent acquisition of the tapes and slides.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1976— 657-695/5375

FORMULAS USED IN CALCULATION OF ORIGINAL FORM A

There were errors in subscripts and summations in the formulas on page 27 of the February 1975 Part III-B. Furthermore, the ASU formula results are expressed in millions of sludge units.

The following formulas supercede and replace those on page 27. Cut out this page on the dotted lines and insert over the existing formulas.

$$ASDT_j = \frac{24 \times AVG_j}{TFL_j}$$

$$ASDT = \sum_{j=1}^{n} ASDT_j$$

$$AWDT = \frac{\sum_{i=1}^{n} AFI_i \sum_{j=i}^{n} ASDT_j}{AFI}$$

$$ATC \times AWDT = \frac{\sum_{i=1}^{n} AFI_i \sum_{j=i}^{n} ASDT_j \times ATC_j}{AFI}$$

$$ASU = 10{,}000 \times AV \times ATC_m$$

NATIONAL WASTE TREATMENT CENTER
CINCINNATI

RETURN SLUDGE FLOW CONTROL

BY

ALFRED W. WEST, P.E.
DIRECTOR - NATIONAL WASTE TREATMENT CENTER

PREPARED FOR THE INTERNATIONAL WORKSHOP ON
INSTRUMENTATION CONTROL AND AUTOMATION
FOR WASTEWATER TREATMENT SYSTEMS

SEPTEMBER 1973

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER PROGRAM OPERATIONS

OPERATIONAL CONTROL OF THE ACTIVATED SLUDGE PROCESS
-RETURN SLUDGE FLOW CONTROL-

Alfred W. West, P.E.

Director,National Waste Treatment Center
(formerly Waste Treatment Branch, National Field
Investigations Center - Cincinnati)
United States Environmental Protection Agency

The return sludge flow, or more precisely, the clarifier sludge flow which includes both return sludge and excess waste sludge flows, should be adjusted to meet measurable process requirements. Attempts to maintain arbitrary return sludge flow percentages, for example 25%, 50%, or 100%, etc., of the wastewater flow will seldom achieve optimum sludge quality and process balance. Fortunately, the results of the one-hour mixed liquor settlometer test, the 15-minute mixed liquor and return sludge centrifuge test, and the final clarifier sludge blanket test reading provide the basic data for simple calculation of the clarifier sludge flow rate needed to maintain or restore process equilibrium.

Symbols Used in Formulas and Calculation Examples

ATC = Aeration Tank Concentration - The mixed liquor concentration determined by the standard 15-minute centrifuge test, expressed as the percent of the centrifuge tube occupied by the compacted mixed liquor sludge.

CFO = Clarifier Flow - Out of Clarifier (Final Effluent)

CFP = Final Clarifier Sludge Flow Percent - (CSF/CFO) From metered values, expressed decimally.

CFPD = Final Clarifier Sludge Flow Percent Demand - Required sludge removal rate as a percent of the final effluent flow (expressed decimally).

CSF = Final Clarifier Sludge Flow - (RSF+XSF)

CSFD = Final Clarifier Sludge Flow Demand - Required sludge removal rate expressed in either cu m/d or mgd.

MLTSS = Mixed Liquor Total Suspended Solids Concentration (mg/l)

RFP = Return Sludge Flow Percent (RSF/CFO as a decimal)

RSC = Return Sludge Concentration - The return sludge concentration determined by the standard 15-minute centrifuge test, expressed as the percent of the centrifuge tube occupied by the compacted return sludge.

RSF = Return Sludge Flow (to aeration tanks)

RSTSS = Return Sludge Total Suspended Solids Concentration (mg/l)

SSC_t = Settled Sludge Concentration - The calculated concentration of the mixed liquor after "t" minutes settling in the settlometer. ($SSC_t = 1000\ ATC/SSV_t$)

SSV_t = Settled Sludge Volume - The volume occupied by the mixed liquor after "t" minutes settling in the settlometer. (cc/l)

XSF = Excess Sludge Flow to Waste

The Clarifier Sludge Flow Demand Formula

In practice, at least once per eight-hour shift, operators should record the actual wastewater and clarifier sludge flow rates, determine mixed liquor settleability by the settlometer test, check the mixed liquor and return sludge concentrations by the centrifuge test, calculate the clarifier sludge flow demand (CSFD) from the following formula, and then adjust the clarifier sludge flow to approximate the demand.

The observed rate at which settled sludge is removed from the final clarifier can be expressed either as the metered flow (CSF) or as a percentage (CSP-recorded as a decimal fraction) of final effluent flow out of the clarifier. The demands (CSFD or CFPD) can also be calculated in terms of flow rates or percentages.

$$\boxed{\begin{array}{l} \text{CSFD} = \text{CSFx(RSC-ATC)/(SSC}_t\text{-ATC)} \\ \text{CFPD} = \text{CFPx(RSC-ATC)/(SSC}_t\text{-ATC)} \end{array}}$$

Sludge Settling (SSV) and Concentration (SSC) Test Data

Mixed liquor sludge concentration characteristics, determined by the settlometer and centrifuge tests, define sludge quality and are used to determine clarifier sludge removal requirements. The settlometer test differs from the conventional sludge settling test for SVI determination in that:

a. A larger diameter (12.5 cm = 5 inches) shorter length (15 cm = 6 inches) graduated cylinder is used to minimize the settling rate distortions that occur when slowly settling sludge is tested in the narrow standard 1,000 cc graduated cylinder.

b. Settled sludge volume is observed and recorded at intervals throughout one hour (or longer for special studies) instead of the single 30-minute reading used for SVI.

c. Sludge quality is revealed by the shape and the end-point (1.0 hr) of the sludge concentration curve that is calculated from the mixed liquor concentration and the settled sludge volumes. (SSC=1,000 ATC/SSV).

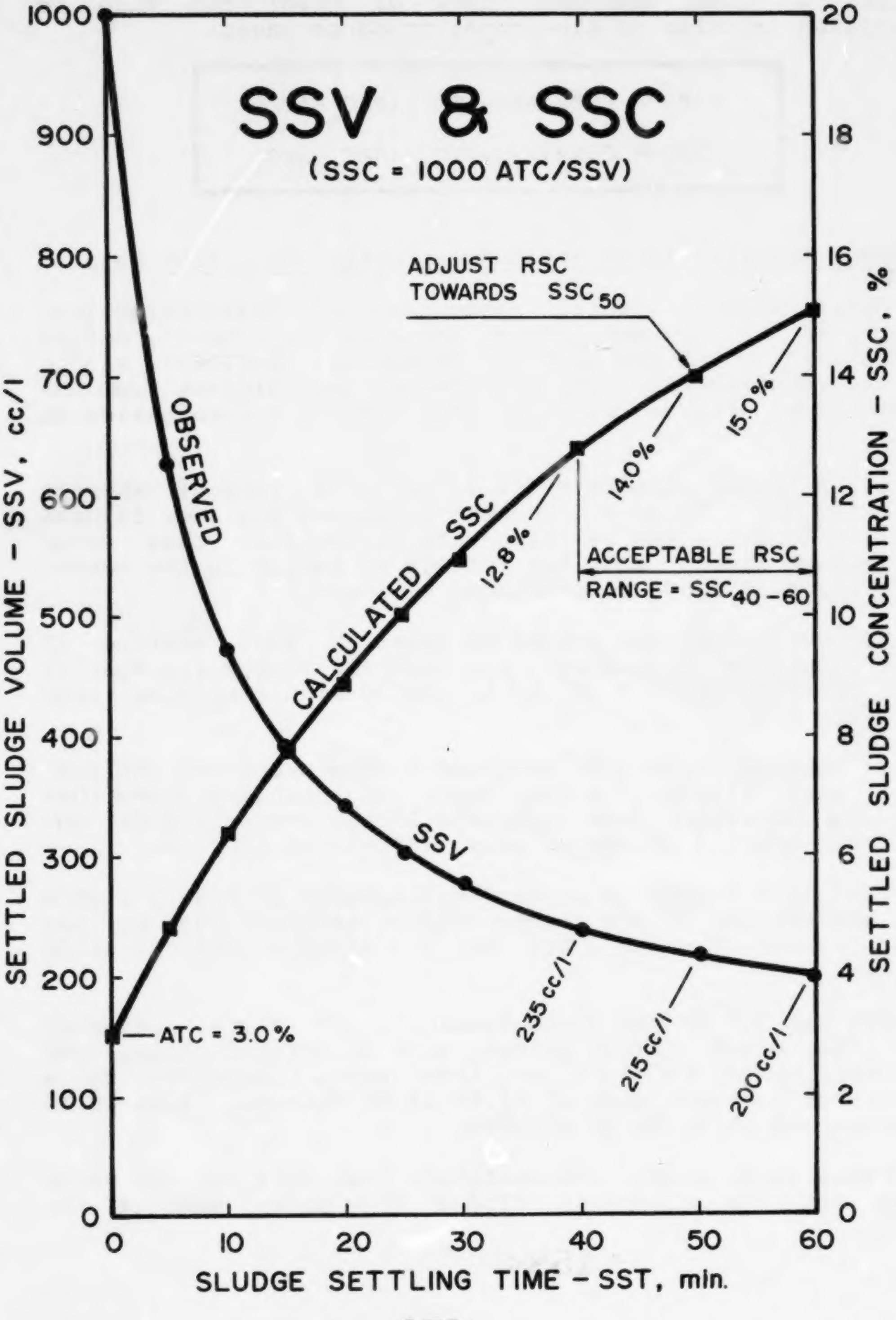
The settlometer test results displayed in Figure 1 show that the Settled Sludge Volume (SSV) reached 235 cc per liter at 40 minutes, 215 at 50 minutes, and 200 at 60 minutes.

The Settled Sludge Concentration (SSC) curve, revealed that the mixed liquor sludge, with an initial centrifuged concentration of ATC=3.0% at time zero, compacted to a calculated concentration of 12.8% in 40 minutes, 14.0% in 50 minutes, and 15.0% in 60 minutes.

Using these sludge concentration test data and the waste water and the clarifier sludge flow meter readings, the

FIG. 1

Sludge Settling and Concentration Characteristics



operator can calculate the clarifier sludge withdrawal rate that will provide approximately one hour sludge compaction time in the clarifier.

Ideally, removing sludge from the final clarifier at a concentration approximating the 60-minute SSC value usually minimizes the sludge detention time in the anaerobic final clarifier environment and reduces the amount of water that is pumped back with the sludge solids to practical minimums. In practice, operators usually use the 50-minute SSC as their target value to minimize the chance of increasing RSC above the 60-minute SSC value and thereby lengthening the clarifier sludge detention time unduly during periods of rapidly rising waste water flows. SSC targets greater or less than the 50 minute value are used only in exceptional cases when other control procedures are also modified to overcome plant or process balance abnormalities.

It may be impractical to try to maintain RSC at the precise target SSC value at all times. The operators, therefore, usually select a range of RSC's, between SSC 40 and SSC 60, within which the clarifier sludge flow is not changed even though RSC does not equal the SSC target value. Therefore, for the sludge concentration characteristics shown in Fig. 1, the operator should change the clarifier sludge flow rate only if the observed return sludge concentration (RSC) value is less than 13% or greater than 15%. If it is, he should insert ATC=3.0 and SSC =14.0 into the clarifier sludge flow demand formula and then adjust the clarifier sludge flow to meet the current demand.

Clarifier Sludge Flow Demand Examples

The following examples illustrate the step-by-step calculation procedures used to determine the clarifier sludge flow needed to achieve process balance where mixed liquor sludge characteristics equalled those in Fig. 1 and the observed return sludge concentration (RSC) equalled 16.0%. Observed flow meter readings are posted in the examples.

Examples

Metric Units

Observed:

ATC = 3.0%
RSC = 16.0%
SSC = 14.0%
CFO = 37,850 cu m/d
RSF = 18,170 cu m/d
XSF = 760 cu m/d

English Units

Observed:

ATC = 3.0%
RSC = 16.0%
SSC = 14.0%
CFO = 10.0 mgd
RSF = 4.8 mgd
XSF = 0.2 mgd

Wanted: CSFD and CFPD required to reduce RSC from 16% to 14%

Therefore:

CSF = RSF+XSF
= 18,170 + 760
= 18,930 cu m/d

CSFD = CSFx(RSC-ATC)
/(SSC$_{50}$-ATC)
= 18,930x(16.0-3.0)
/(14.0-3.0)
= 18,930x1.18
= 22,340 cu m/d

CFP = CSF/CFO
= 18,930/37,850
= 0.50

CFPD = CFPx(RSC-ATC)
/(SSC$_{50}$-ATC)
= 0.50x1.18
= 0.59
= 59%

Therefore:

CSF = RSF+XSF
= 4.8 + 0.2
= 5.0 mgd

CSFD = CSFx(RSC-ATC)
/(SSC$_{50}$-ATC)
= 5.0x(16.0-3.0)
/(14.0-3.0)
= 5.0x1.18
= 5.91 mgd

CFP = CSF/CFO
= 5.0/10.0
= 0.50

CFPD = CFPx(RSC-ATC)
/(SSC$_{50}$-ATC)
= 0.50x1.18
= 0.59
= 59%

The operator should now increase the clarifier sludge removal pumping rate from 18,930 cu m/day (5.0 mgd) to 22,340 cu m/day (5.9 mgd). In actual practice, operators usually select a maximum allowable sludge flow increase, or decrease, that they will not exceed at any single test and control period. In this case of a 37,850 cu m/d (10.0 mgd) plant, for example, the maximum clarifier sludge flow adjustment permitted after each test period might have been limited to 3,785 cu m/day (1.0 mgd). This is a precaution against over-control that could otherwise occur if very large flow changes are called for.

During the next 8-hour shift, or more frequently if necessary, the operator would make similar observations and calculations and then readjust, if necessary, the clarifier sludge flow to meet the new demand.

During each testing period the operator should also calculate the sludge detention time in the final clarifier and attempt to maintain this value between 30 and 90 minutes. If the process is so badly unbalanced that the clarifier sludge detention time equalled or exceeded two hours, he should increase the clarifier sludge flow rate more aggressively and probably also step up the sludge wasting rate. The clarifier sludge flow demand, discussed in this paper, must be coordinated with other measurable process requirements that will be described in a forthcoming PROCESS CONTROL pamphlet being developed by the National Waste Treatment Center.

Control adjustments could be accomplished more conveniently and accurately if the treatment plant were equipped with an automatic clarifier sludge flow rate controller that continuously adjusted the metered clarifier sludge flow to equal a preset percentage of the measured waste water flow. In such case, the operator would move the controller set-point from 50% to 59% and the increased sludge flow rate would continue to respond to waste water flow rate changes.

Looking to the future, it is easy to visualize how this procedure may be further automated when reliable continuous activated sludge concentration sensors become available.

Response to Return Sludge Flow Adjustments

The return sludge concentration and the mixed liquor sludge concentration responses to changed return sludge flow percentages are illustrated in Figures 2 and 3, which contain two weeks of data from the Merrimack, New Hampshire, Waste Treatment Plant operating log. During the period, the return sludge percentage was increased from 15 to 127, and then reduced to less than 26.

Return Sludge Concentration (RSTSS in mg/l)

Return sludge concentrations respond rapidly and inversely to return sludge flow adjustments. This normal relationship is evident in Figure 2 where the return sludge concentration fell from 5640 to 2280 mg/l while the return sludge percentage increased. Return sludge concentration then increased to 7110 mg/l while the return sludge percentage was reduced.

Mixed Liquor Concentration (MLTSS in mg/l)

Mixed liquor concentrations, and the associated sludge-age and food-to-microorganism ratios, respond strongly to sludge wasting adjustments but they are not normally affected greatly by return sludge flow adjustments unless the process is badly out of balance. In fact, a direct response, where mixed liquor concentrations increase with higher return sludge flows, usually occurs only after the process balance has been upset by excessive accumulations of sludge solids in the final clarifier.

As shown in Figure 3 the mixed liquor concentration increased only modestly from 1230 to 1470 mg/l while the return sludge flow percentage rose drastically from 15 to 127. Then, the mixed liquor concentration continued to increase to 2400 mg/l even though the return sludge percentage adjustment was reduced from 127 to 37.

Sludge Concentrations vs. Sludge Wasting

Process response to variations in sludge wasting is discussed only briefly since Sludge Wasting Control is beyond the scope of this paper.

Comparison of the mixed liquor and the return sludge concentration curves with the pounds of sludge wasted curve (Figure 4) reveals that the effects of wasting were overwhelmed by other control adjustments from July 17 to

FIG. 2

Return Sludge Concentration Response to Return Sludge Flow Percentage Adjustments

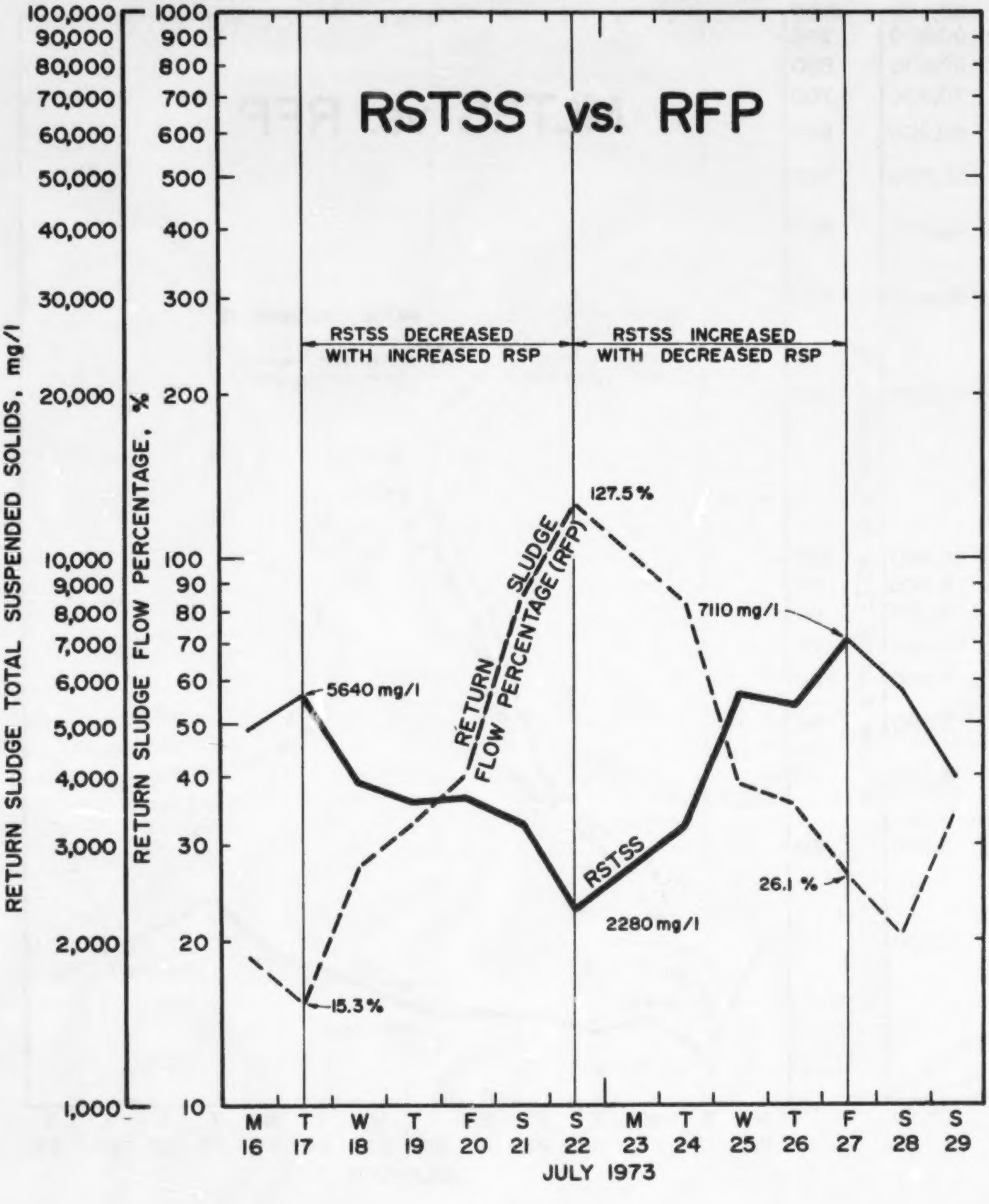


FIG. 3

Mixed Liquor Concentration Response to Return Sludge Flow Percentage Adjustments

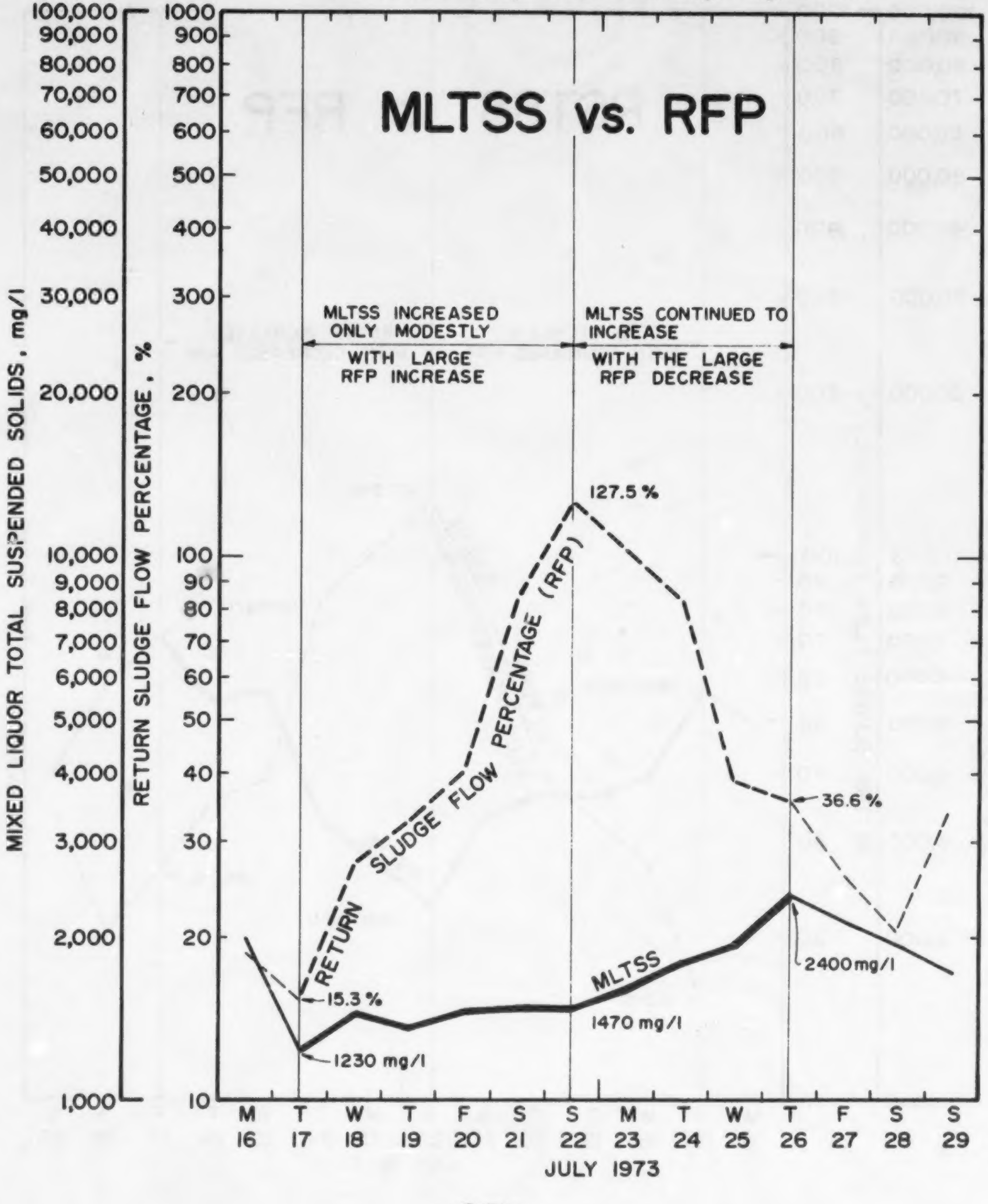
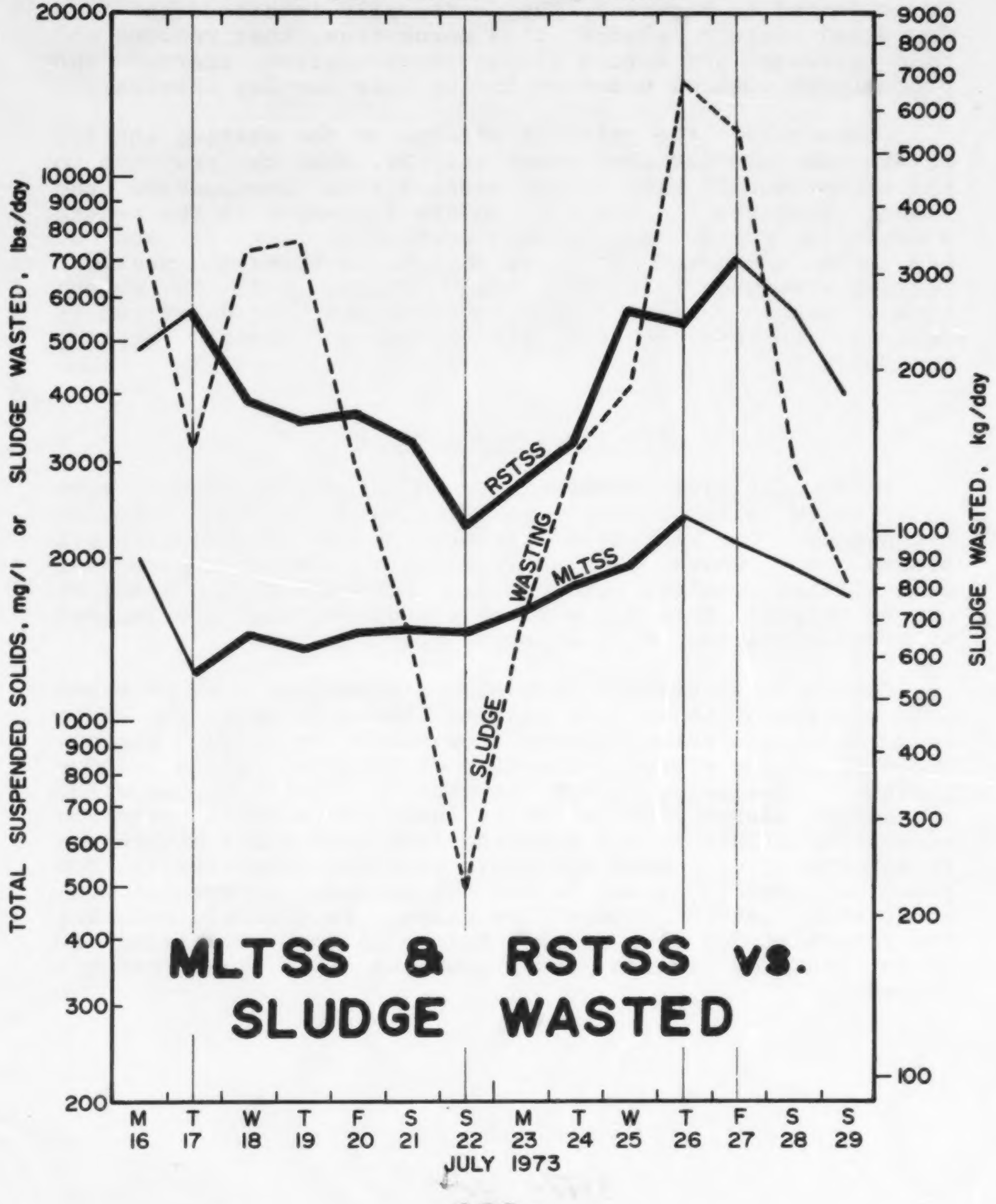


FIG. 4

Mixed Liquor and Return Sludge Concentrations vs. Kilograms (Pounds) of Sludge Wasted



July 26. The sludge concentrations did not increase with the decreased wasting rates, nor did they decrease with the increased wasting rates to the extent they should have if sludge wasting had exerted the principal control pressure. As evidenced in Figure 2, the drastically increased and then decreased return sludge flow percentage, that reduced and then increased the return sludge concentration, exerted the predominant control pressure during this ten-day interval.

Conversely, the relative effects of the wasting and the return controls reversed after July 26, when the response to the exceptionally high sludge wasting rate overpowered the lesser response to the more moderate changes in the return sludge flow percentage. Sludge wasting on July 26 and 27 had been increased to more than three times the previous ten-day average. Both the mixed liquor and the return sludge concentration trends reversed and then decreased in logical response to the predominating sludge wasting control.

Practical Precautions

This clarifier sludge flow adjustment procedure, when coordinated with proper aeration and sludge wasting techniques, has improved performance at practically all plants at which Waste Treatment Branch personnel demonstrated control procedures. Although such procedures can be helpful, they may not solve problems that are imposed by gross overloads or by improper plant design.

Furthermore, certain hydraulic limitations must be taken into consideration at most plants. There is usually a limit below which the return sludge flow cannot be reduced without impeding proper sludge collection or plugging return sludge piping. Similarly, there is usually a limit beyond which the return sludge flow cannot be increased without creating excessive turbulence and scouring flow velocities within the final clarifier. Most operators identify these limits from practical experience and follow the demands throughout the acceptable return sludge flow range. In general, reducing the return sludge flow percent below 15 or increasing it above 150 may induce more problems than those that are solved.

Actual Results

Two examples of final effluent quality achieved while following these control procedures are the most recent 30-day average data summaries from the Merrimack, New Hampshire, and the Albany, Oregon, waste water treatment plants. The National Field Investigation Center's technical support projects were completed on September 30, 1973, at Merrimack and on August 9, 1973, at Albany.

The Merrimack plant treats 8,330 cu m/day (2.2 mgd) of wastes. About 95% of the flow is brewery waste and the remainder comes from a paper coating factory. Wastes are pretreated by a trickling filter before entering the complete-mix type, activated sludge plant equipped with surface-mechanical aerators.

The Albany plant treats 20,820 cu m/day (5.5 mgd) of domestic sewage. Local industries contributed less than 5% of the waste flow during the project. The plant is a conventional complete-mix activated sludge plant utilizing compressed air.

During the first two months of each project, NFIC-C personnel trained plant personnel to use the coordinated control procedures that have been developed by the Waste Treatment Branch. Consultation was provided for the next month or two and the final month's performance, summarized in the Table 1, was achieved by plant personnel without further assistance from NFIC.

TABLE 1 Activated Sludge Plant Performance

	Merrimack		Albany	
	BOD	SS	BOD	SS
Concentrations (mg/l)				
Raw Waste	1168	524	191	254
Aerator Influent	340	325	141	172
Final Effluent	6.9	6.4	5.4	6.0
Reductions (%)				
Preliminary Treat.	70.9	38.0	26.2	32.3
Act. Sludge Process	98.0	98.0	96.2	96.5
Total Plant	99.4	98.8	97.2	97.6

The turbidity of settled final effluent averaged 1.8 JTU at Merrimack and 2.1 JTU at Albany.

Summary

The real value of this control procedure is that it responds to practically all loading, process balance and sludge quality characteristics to reveal the clarifier sludge flow rate that will best satisfy the net requirement of all these interacting variables. The calculated demand satisfies the coordinated requirements imposed by changing mixed liquor sludge concentrations and quality, sludge solids distribution between the aeration tanks and the final clarifiers, and the waste water flow rates. On a progressive long-term basis it also responds to changes in organic loadings and the interrelated sludge-wasting rates. This control procedure satisfies the dynamic requirements of the total process.

Author's Note

A series of pamphlets describing Operational Control Procedures for the Activated Sludge Process is being developed by the National Waste Treatment Center - Cincinnati. Part I - OBSERVATIONS, Part II - CONTROL TESTS, Part III-A&B CALCULATION PROCEDURES and APPENDIX are available for distribution. Part IV - SLUDGE QUALITY, Part V - PROCESS CONTROL, and a series of CASE HISTORIES will come later. This paper is essentially a preview of a section of proposed Part V - PROCESS CONTROL. Though this paper is limited to a discussion of the clarifier sludge flow control procedures that were evolved by me and are demonstrated by the National Waste Treatment Center, it should be recognized that coordinated control of aeration tank mixing and dissolved oxygen concentrations along with excess sludge wasting procedures is also necessary to obtain best plant performance and effluent quality from the activated sludge process.

Alfred W. West

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OPERATIONAL TECHNOLOGY BRANCH
NATIONAL TRAINING AND OPERATIONAL TECHNOLOGY CENTER

UPDATED SUMMARY
# of the
OPERATIONAL CONTROL PROCEDURES
for the
ACTIVATED SLUDGE PROCESS

by
Alfred W. West, P.E.
Chief, Operational Technology Branch

JANUARY 1978

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER AND HAZARDOUS MATERIALS

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OBJECTIVES

This summary provides a current digest of the coordinated activated sludge plant control procedures that have been found most useful by the Operational Technology Branch during on-site plant operations and operator training programs.

NEW SECTIONS

Certain new sections summarize most of what will be presented in the proposed **Part IV – Sludge Quality** and **Part V – Operational Control** issues of the pamphlet series. The objective is to present this information now, even though on-going assessment of unique field operations experiences continues to delay final preparation of Parts IV and V.

RETURN SLUDGE FLOW CONTROL UPDATE

It also updates the original **September 1973 Return Sludge Flow Control** pamphlet. The procedures described in the original pamphlet have proven successful when applied to activated sludges of fair to good quality. But they led to unsatisfactory over-control when applied directly to extremely fast settling sludges that compacted to very high concentrations and to extremely slow settling sludges that compacted hardly at all. This update identifies sludge quality and presents a modification that makes the return sludge flow control procedures effective for most all types of sludges encountered in actual practice.

PAST AND FUTURE

A brief digest of the previously distributed pamphlets on Observation and Control Tests is also included for continuity of the discussions.

And finally, this Summary and the previously distributed Parts of the pamphlet series may be modified and expanded when additional useful process control procedures are developed and confirmed by on-site plant operation experiences.

BASIC CONCEPTS

These operational control procedures were developed to help activated sludge plant operators satisfy all significant interrelated process requirements *simultaneously*. Information provided by simple control tests reveal the *coordinated* control adjustments needed to maintain or restore optimum process balance, sludge quality and final effluent quality. Conversely, the process is *not* controlled by attempting to achieve *preconceived* levels of *individual* variables such as, mixed liquor sludge concentration, mean cell residence time and food to microorganism ratios, etc.

Perceptive observations of aeration tank foams and final clarifier surface characteristics usually indicate *long-term* control requirements. *Control* tests such as, final clarifier sludge blanket depth determinations, mixed liquor and return sludge concentration (by centrifuge) and sludge settleability are used to define sludge quality and process status. Control adjustment requirements are determined from the control test data. Trend charts of sludge settleability (SSV) and compactability (SSC), mixed liquor and return sludge concentrations, sludge wasting, final effluent turbidity, and other informative parameters are maintained to reveal process responses to the control adjustments.

Conventional parameters such as food to microorganism rations (F/M) are calculated and sludges are observed under the microscope for *monitoring* and comparative purposes, but are not used directly for process control. Thirty-minute sludge volume indices (SVI) or the corresponding sludge density indices (SDI), which do not reveal as much about sludge quality as do the more descriptive **SSC** curves, are not used at all.

The control tests (depth of blanket, settlometer and centrifuge, etc.), nomenclature and many process relationship calculations are those proposed by E. B. Mallory in the 1940's. The subsequent procedures to determine the required interrelated process control requirements were evolved by the author.

> *Best process performance is achieved by satisfying all interrelated process requirements simultaneously; not by exclusive dependence upon any single or preconceived factor.*

Preparation of the EPA pamphlet series entitled **Operational Control Procedures for the Activated Sludge Process**, describing these procedures used by the Operational Technology Branch (formerly NFIC-C) of the Municipal Operations and Training Division, continues. A listing of the completed pamphlets presently available is appended.

OBSERVATIONS
(Discussed in "Part I")

The type of foam observed on the aeration tank surface and the characteristic type of sludge solids, if any, observed rising to the final clarifier water surface usually reveal the *long-term* activated sludge wasting requirements. Conclusions reached from such observations must, however, be confirmed by the results from the other control tests before the wasting rates are actually changed. Under certain circumstances, discussed later under Sludge Wasting for Slow Settling Sludge, *temporary short-term* wasting adjustments that differ from the overall long-term needs must be imposed to satisfy the *immediate* process requirements.

AERATION TANK FOAM

Voluminous, white billowing foam reveals that the sludge is too young and indicates that sludge wasting should be reduced (to increase sludge age) on a *long-term* basis within the next few weeks to one month. Such a reduction should not be started, however, until final clarifier performance and results from the control tests confirm the ability to do so without forcing sludge solids out over the clarifier effluent weirs.

Dark brown, scummy foam usually accompanies old sludge that should be wasted from the system. If confirmed by final clarifier performance and control test data, sludge wasting should be increased about 15 to 20 percent per day until acceptable sludge quality is produced.

FINAL CLARIFIER SURFACE

Here again, the process control requirements indicated by the appearance of the final clarifiers must be checked with and confirmed by the control tests before any significant changes are made.

Clean Surface, Clear Effluent

Operators should not argue with success while producing an excellent final effluent. Except for some minor fine tuning, they should continue their proven control strategy unless and until the sludge blanket starts moving up towards the tank surface. The control tests, which will warn of impending danger long before serious problems occur, will indicate the corrective control modifications that may be needed if, and when, the process starts to deteriorate.

Ashing and Clumping

Small sludge particles (called "ashing") or large sludge globs (called "clumping"), that break away from the settled sludge blanket and rise to the clarifier water surface almost always indicate that the sludge is too old. This condition, which usually occurs when a fully, or overly, oxidized sludge denitrifies in the final clarifier, indicates the need for increased sludge wasting.

Sludge Solids Washout (with good sludge quality)

Sludge solids being drawn over the effluent weirs from a high sludge blanket may indicate a number of causes and possible solutions. Excessive raw waste flows, unequal mixed liquor flow into, or return sludge flow out of multiple clarifiers, and improperly located overflow weirs can induce this problem *even with excellent sludge quality*. Solution of these hydraulic problems may require infiltration-inflow elimination, installation of suitable meters and control devices, and possibly plant modifications and additions.

If wastewater flows are within reasonable limits, the control tests will show whether the solids washout could have been caused by too high or too low return sludge pumping rates.

Bulking Sludge

True bulking (where slow settling, usually light tan colored, sludge is drawn out over the effluent weirs) practically always indicates that the sludge is too young. Sludge wasting should be reduced on a *long-term* basis and the control tests will indicate the *immediate* and day-to-day process control requirements.

CONTROL TESTS
(Discussed in "Part II")

The clarifier sludge blanket depth observations, the centrifuge test of mixed liquor and return sludge concentrations, and the settlometer test for mixed liquor sludge settleability define sludge quality and process status. Control adjustment requirements are determined from the results of these *control* tests. Mixed liquor D.O. is determined conventionally, and is normally maintained in the 2 to 4 mg/1 range. Final effluent quality is monitored by turbidity tests to reveal plant performance responses to the control adjustments. Other important *monitoring* tests such as, BOD and suspended solids are also run, but are not used directly for control purposes.

The settlometer test should be run at least once per day, and preferably once per shift. The centrifuge, depth of sludge blanket and final effluent turbidity tests should be run at least once per 8-hour shift, and more frequently during troublesome periods.

SLUDGE QUALITY
(To be discussed in a forthcoming "Part IV" of the pamphlet series.)

Sludge quality is defined by the shape and endpoint concentration of the settled sludge concentration curve that is developed from the settlometer and centrifuge control test data.

Figure 1 displays a family of Settled Sludge Volume (SSV) and Settled Sludge Concentration (SSC) curves for the three different generalized types of activated sludge at similar mixed liquor concentrations.

The upper set of Settled Sludge *Volume* curves are graphic presentations of the settlometer test data. In actual practice, settlometer tests are usually terminated after one hour for "Rapid" to "Normal" sludges and continued longer only for "Slow" sludges.

Activated sludge quality, however, is defined by the shape of the Settled Sludge *Concentration* curves that are calculated from the SSV and the ATC control test data.

The Aeration Tank mixed liquor Concentration (ATC) and the Return Sludge Concentration (RSC) are determined by a 15-minute centrifuge test.

The SSC value for any SSV value is:

$$\mathrm{SSC} = \frac{1000\ \mathrm{ATC}}{\mathrm{SSV}}$$

A set of settled sludge concentration (SSC) curves for "Rapid", "Normal" and "Slow" settling activated sludges, developed from the upper SSV curve data at ATC = 4.0, is illustrated in the lower portion of Figure 1.

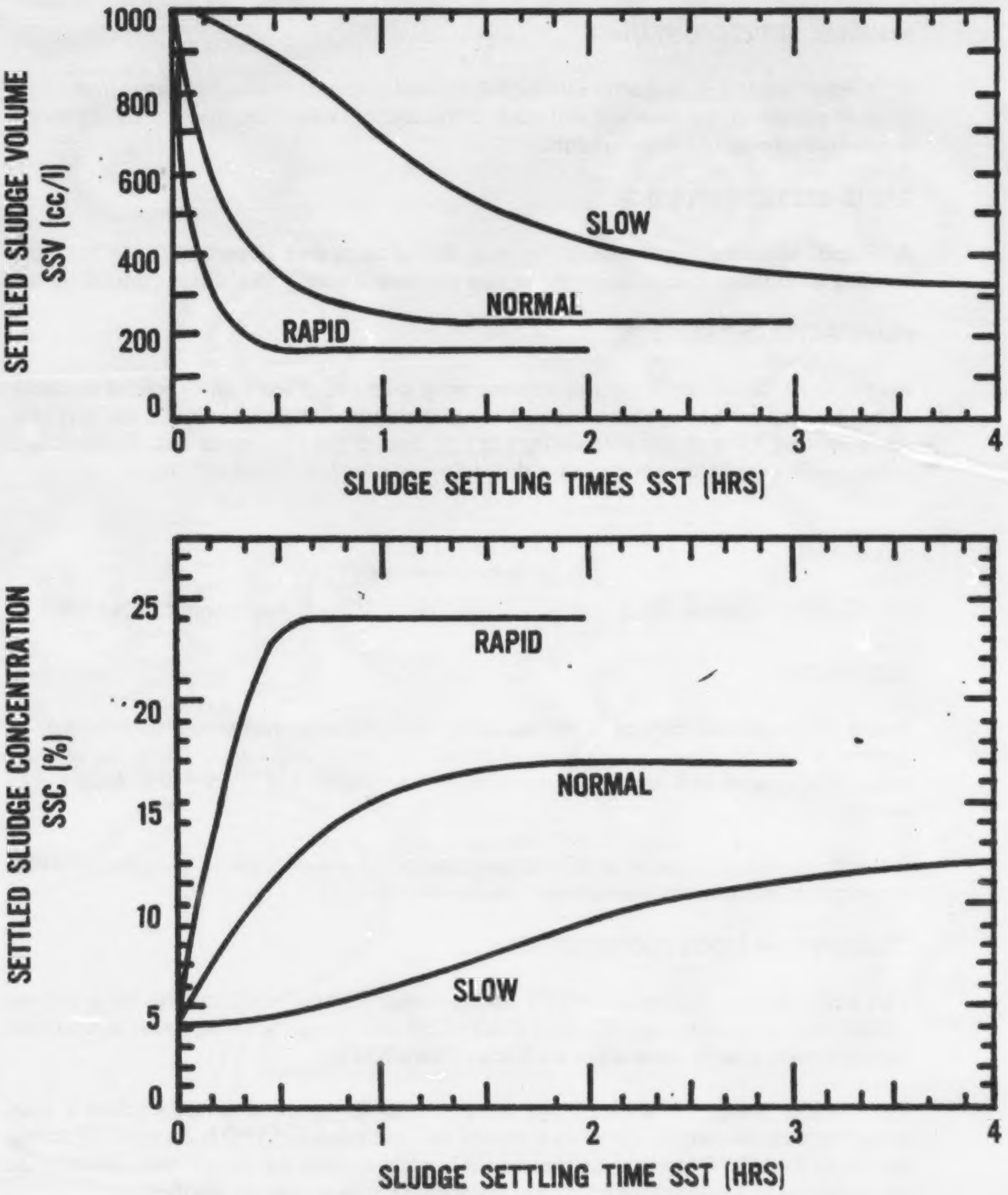

FIGURE 1.– SSV and SSC CURVES for Slow, Normal and Rapid settling and concentrating activated sludges.

NORMAL SETTLING SLUDGE

A "Normal" settling good quality activated sludge will concentrate to an SSC range from about 12 to 18 percent in one hour and will reach ultimate compaction (i.e., won't settle any more) somewhere between one and two hours.

RAPID SETTLING SLUDGE

A "Rapid" settling sludge, concentraing to an SSC of more than 20 percent in one hour and reaching its endpoint concentration in less than one hour is usually an old over oxidized sludge.

SLOW SETTLING SLUDGE

An extremely "Slow" settling sludge, concentrating to an SSC of less than 10 percent is usually a young sludge. Such a sludge may not settle at all during the first 5 or 10 minutes and may only reach between 700 and 900 cc/1 during the first hour of the settlometer test. Furthermore, settling and compaction continues, though at a slow rate, for 3 to 4 hours or longer.

PROCESS CONTROL

(To be discussed in a forthcoming "Part V" of the pamphlet series.)

AERATION

Except for clumping or bulking conditions (when DO's should be maintained below 1.0 mg/1), blowers or aerators should normally be set to maintain about 2 to 4 mg/1 DO in the aeration tanks. The aeration tank contents must be mixed thoroughly and continuously from top to bottom.

It may be necessary to change air diffuser types and locations and modify or replace mechanical aerators if the aeration *and mixing* requirements cannot be met.

CLARIFIER SLUDGE FLOW CONTROL

This section updates the September 1973 **Return Sludge Flow Control Pamphlet**. Here, process control is discussed in terms of Clarifier Sludge Flow *Percentages* (CSP expressed as a decimal fraction) rather than in terms of Return Sludge *Flows* (RSF).

The Clarifier Sludge Flow Percentage Demand (CSPD) equations actually reflect a mass balance around the clarifier, rather than around the aeration tank. CSPD is the new CSP setting needed to force RSC towards the desired SSC_t while keeping the sludge units entering the clarifier equal to the sum of the return and waste sludge units leaving the clarifier.

Furthermore, the control demands are calculated in terms of clarifier sludge flow *percentages* (CSP) instead of the clarifier sludge *flow* (CSF) rates. The CSP demand can be used directly as the set-point value for flow-pacing, automatic return sludge flow controllers. The CSP demands must obviously be converted to sludge *flow* rates (based on wastewater flows) for manually-controlled return sludge pumps.

An optimum Clarifier Sludge Flow Percentage (CSP) can practically always be determined for the specific circumstances prevailing at any individual plant:

$$\text{CSP} = \frac{\text{Return Sludge Flow} + \text{Waste Sludge Flow}}{\text{Wastewater Flow}}$$

The optimum CSP range will be governed by sludge quality; but the practical application ranges will be limited by the final clarifier size, equipment and design features.

Clarifier sludge flow percentages should be adjusted to optimize the time sludge remains in the anaerobic final clarifier environment and minimize the amount of water pumped with the sludge. At normal to high wastewater flow rates (especially with slowly settling sludges) proper clarifier sludge control will hold the sludge blanket as low as possible in the final clarifier. It will also help induce proper sludge oxidation rates, overall plant performance and final effluent quality.

Sludge quality will be degraded if CSP is adjusted either too much lower or too much higher than the optimum range. Too low a CSP will usually hold excessive sludge quantities in the clarifier, increase the sludge blanket thickness and probably induce sludge septicity. Conversely, too high a CSP will increase turbulence within the final clarifier, decrease aeration tank detention time and (especially for slow settling sludges) also increase the sludge blanket thickness. Of the two, a CSP that is lower than optimum can degrade plant performance more than a CSP that is higher than optimum. Since precise optimums can seldom be maintained in practical operations, CSP should be adjusted towards the high side rather than towards the more dangerous low side of the acceptable CSP range.

The Settled Sludge Concentration (SSC) curve data is used to calculate the CSP adjustments that are needed to satisfy the actual process requirements. The SSC range for CSP control is shown on Figure 2. CSP should be controlled to force the measured return sludge concentrations (RSC) towards the settled sludge concentration (SSC) reached near the upper portion of the curved segment of the SSC curves for "Rapid" and "Normal" sludges. RSC should usually be forced to the segment near the inflection point on the SSC curve for "Slow" sludges. The segments of the SSC curves within the shaded area of Figure 2 identify the CSP control ranges for the intermediate types of activated sludges.

The optimum CSP range will be dictated by mixed liquor sludge concentrations, sludge quality, wastewater flows and loadings. Too high a CSP can at times be almost as harmful as too low a CSP. *Arbitrarily* increasing CSP whenever clarifier sludge bulking occurs can frequently intensify rather than cure the problem.

But conversely, CSP adjustments do not significantly alter food to microorganism ratios (F/M) in a properly balanced system. *F/M is controlled by wasting.* Mixed liquor concentrations will be increased significantly by increasing CSP only if excessive sludge solids had been permitted to pile up in the final clarifier previously while CSP had been reduced too low.

In a balanced system, the 24 hour average mixed liquor concentration (ATC) remains fairly constant from day to day regardless of normal CSP adjustments. ATC is, however, increased by this reduced early morning wastewater flows and decreased by the increased midday flows. The return sludge concentration (RSC), however, changes predictably and rapidly, in response to CSP adjustments.

Normal Settling Sludge

For "Normal" Settling, good quality sludges (SSC in the 12 to 18 percent range) CSP, based upon the sum of the return sludge and waste sludge flow rates, should be adjusted to force the observed RSC within the 40-minute to 60-minute SSC range of the SSC curve.

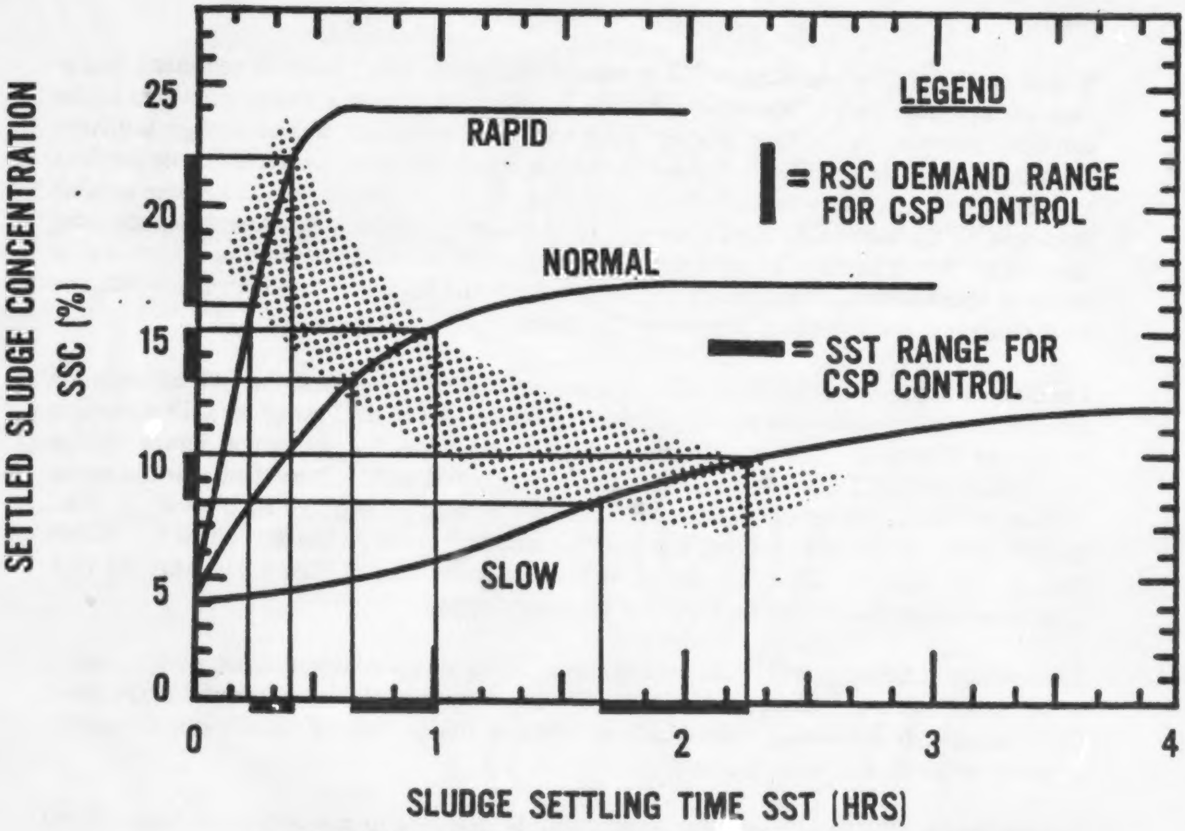

FIGURE 2. SSC RANGE FOR CSP CONTROL

The "Normal" sludge illustrated in Figure 2 concentrated to the 13–15 percent SSC range after 40 to 60 minutes settling time. CSP should, therefore, be adjusted to force the return sludge concentration (RSC) within this 13 to 15 percent range.

Increase CSP to reduce RSC
and
Reduce CSP to increase RSC

The rationale of the following Clarifier Sludge Flow Demand (CSFD) calculation example is discussed in Part III-A.

After reading the flow meters and performing the control tests, the proper clarifier sludge flow requirement (CSPD) can be calculated from the following formula:

$$\mathrm{CSPD} = \mathrm{CSP} \times \frac{\mathrm{RSC} - \mathrm{ATC}}{\mathrm{SSC}_t - \mathrm{ATC}}$$

CSPD is the Clarifier Sludge Flow Percentage Demand, CSP is the observed Clarifier Sludge Flow Percentage and SSC_t is the SSC concentration at the selected settling time (t). Other terms have been identified previously.

To illustrate, assume that:

Waste Water Flow = 1.20 mgd
Metered CSF = 0.48 mgd
Observed RSC = 17.5
Observed ATC = 5.0
Desired SSC_{60} = 15.0 @ the 1-hour SST (for the selected t = 1.0 hr.)

From the mixing formula:

$$\mathrm{CSP} = \frac{\mathrm{ATC}}{\mathrm{RSC} - \mathrm{ATC}}$$

$$= \frac{5.0}{17.5 - 5.0} = 0.40$$

(i.e. 40% of the wastewater flow)

From the CSPD formula:

$$\mathrm{CSPD} = \mathrm{CSP} \times \frac{\mathrm{RSC} - \mathrm{ATC}}{\mathrm{SSC}_t - \mathrm{ATC}}$$

$$= 0.40 \times \frac{17.5 - 5.0}{15.0 - 5.0}$$

$$= 0.40 \times 1.25 = 0.50 \text{ (i.e., 50\%)}$$

In this case the set-point of an automatic sludge flow controller would be increased by a factor of 1.25 to increase the clarifier sludge *percent* from its original 40% setting to the new 50% requirement.

Under manual control, the metered clarifier sludge *flow* would be increased by the same 1.25 factor from 0.48 to 0.60 mgd for the 1.20 mgd wastewater flow.

Rapid Settling Sludge

The clarifier sludge flow should be adjusted to force RSC towards the 15 to 20-minute SSC value when the sludge settles too rapidly. (when SSC_{60} exceeds 20 percent as shown in Figure 2)

It would be imprudent to try and force RSC to the 1-hour SSC value on the flat portion of the SSC curve. The curve reveals that the sludge could be piled up, and held, in the clarifier for 2 or more hours if the return sludge concentration were brought up to, or slightly over, this 60-minute SSC level of 24 percent.

Slow Settling Sludge

Selection of the proper SSC and CSP target values for return sludge flow control is more critical for slowly settling sludges than for the other two types.

Additional calculation procedures that the author has developed to help select the appropriate SSC target value from the SSC curve are described in the "BLT vs CSP" supplement to the pamphlet series. Additionally, here is an orderly "cut-and-try" procedure that can be used if sludge quality and ATC do not change significantly while determining the proper CSP value.

Start out by adjusting the CSP for force RSC to some SSC value in the range between the 2-hour and 3-hour SSC values on the SSC curve. The 2-hour SSC is usually a good starting point.

Then observe the clarifier Depth Of Blanket (DOB), the mixed liquor concentration (ATC) and the return sludge concentration (RSC) critically. If the sludge blanket is lowered by this adjustment, you are on the right track.

Then decrease CSP about 15 to 25 percent of its former value per day for the next 2 or 3 days. If the sludge blanket level is reduced after each CSP adjustment, continue moderate clarifier

180<

sludge flow reductions until the lowest blanket level is achieved. CSP should have been optimized at this lowest sludge blanket level. If CSP is reduced too low, however, sludge will pile up in the clarifier and the blanket level trend will usually reverse and start rising towards the clarifier surface. A reduction of CSP below the critical level will also be revealed by significantly reduced ATC values.

Reverse the above procedure if reducing clarifier sludge flow did not help. Start increasing CSP moderately, day by day until the lowest sludge blanket level is obtained. This should occur at optimum CSP. Here again, the blanket will also start rising if CSP is increased too high.

This "wiggling-in" procedure should reveal the proper SSC, RSC and CSP needed to minimize bulking hazards and (with properly coordinated sludge wasting) and improve sludge quality and settleability.

CSP Control Strategies

The clarifier sludge flow percent demand (CSPD) control strategy is similar for practically all varieties of sludge quality. It is straightforward for "Normal" and "Rapid" sludges, where CSPD can be calculated directly from the demand formula but the additional "wiggling-in" intermediate step may be necessary for "Slow" sludges. The shaded area intersecting the three SSC curves on Figure 2 shows the probable SST-SSC ranges for sludge qualities intermediate between rapid and normal, and between normal and slow sludges.

Normal Sludges

An SSC$_t$ value within the 40–60 minute SST range can be plugged directly into the clarifier sludge flow percentage demand formula (CSPD) to determine the CSP needed to achieve optimum process balance for most normal sludges.

Rapid Sludges

Similarly, calculating CSPD for the 15–20 minute SSC value will be appropriate for the rapid sludges.

Slow Sludges

The SST – SSC control range, which is not usually revealed as clearly by the "Slow" SSC curves, must be determined before the SSC target value can be selected for use in the CSPD formula. The "wiggling-in" procedure, described previously, will establish both the proper SST - SSC range and the CSP values for the sludge represented by the SSC curve. Subsequently, as long as sludge quality remains fairly constant, the SSC target determined previously by the wiggling-in procedure can be plugged into the CSPD formula to determine the CSP requirements to adjust for changes in mixed liquor concentrations (ATC). Finally, the CSPD formula can once again be used directly when sludge quality improves and approaches the "Normal" status.

General Conditions

Clarifier size and hydraulics may limit the range of practical CSF adjustments. Regardless of calculated demands, CSF should not be reduced to the level where slowly moving, thick clarifier sludge will plug the sludge withdrawal pipes. Nor can the CSF be reduced significantly below the level where the clarifier *sludge* detention time (CSDT) consistently exceeds the *clarifier* detention time (CDT - based on wastewater flow plus clarifier sludge flow) in hydraulically overloaded small clarifiers. Clarifier Sludge Detention Time (CSDT) calculations are illustrated in Part III-A of the pamphlet series.

Furthermore, it is usually preferable to make the total calculated clarifier sludge flow adjustment in two or more intermediate steps, about 1 or 2 hours apart, whenever the demand calculations call for much more than 25% CSP changes. And finally, it is good practice to increase the low nighttime clarifier sludge flow rates to approach the anticipated higher CSP demands before, rather than hours after, the increased daytime wastewater flows actually reach the plant.

Here are some additional facts that have been found helpful:

> CSP has been reduced too low if RSC remains substantially constant while either, or both, clarifier sludge or wastewater flow rates change significantly. This usually occurs when excessive sludge, that has reached maximum compaction, is piled up in the final clarifier.
>
> CSP has also been reduced too low if ATC is lowered substantially after the clarifier sludge flow has been reduced (with fairly "constant" wastewater flow and sludge wasting). In this case some of the sludge that would normally have remained in the aeration tanks under balanced conditions has been transferred to and piled up in the clarifiers by reducing CSP too low.

Clarifier Sludge Flow Control Summary

1. Determine return sludge flow control requirements from the sludge quality and SSC Concentrations revealed by the SSC curves.

2. Force RSC (by proper return sludge percent adjustments) to approach the following guideline SSC values:

   "Rapid" Settling Sludge . . . . 15 to 20 min. SSC
   "Normal" Sludge . . . . 40 to 60 min. SSC
   "Slow" Settling Sludge . . . . . Start by approaching the 2-hour SSC and then "wiggle-in" to the best value.

SLUDGE WASTING CONTROL

Activated sludge wasting practice strongly influences sludge quality and overall plant performance. It is frequently the "tail that wags the entire dog." Many otherwise satisfactory activated sludge plants are seriously degraded by an inability to waste excess sludge from the process.

This section describes an orderly procedure to control sludge wasting by day-to-day evaluation of the trend charts. In other words, the operator can usually use the basic control test data to determine whether to hold, increase or decrease wasting. The direction and the rate at which the sludge quality (SSC) and sludge age have responded to previous wasting (XSU) adjustments will be revealed by the SSC and XSU trend charts. The progressive trend chart relationships will then indicate when the corrective wasting schedule should be readjusted.

> *Proper wasting control depends upon satisfying the true process requirements that vary with loading changes and are altered by control adjustments.*
>
> *Properly coordinated wasting control is seldom achieved by attempting to establish independent preconceived levels of mixed liquor concentration, F/M, or sludge age.*

Normal Settling Sludge

Continue the established wasting rate if the sludge is concentrating to the desirable 14 to 16 SSC range, the blankets are deep down in the final clarifier and the final effluent is clear and solids free. The end results have proven that the true process requirements have been satisfied for the prevailing circumstances.

Wasting schedules should be adjusted to meet the new demands when the trend chart comparisons show that sludge quality and process balance are starting to shift away from optimum.

Rapid Settling Old Sludge

Sludge that concentrates too rapidly (i.e., SSC exceeds 20 percent in less than 1 hour) can most always be slowed down to a lower and more desirable SSC range by increasing the sludge wasting rate to reduce sludge age. But the wasting rate should be increased gradually (about 15 percent per day) to *progressively replace* the older sludge with younger, slower settling sludge.

Two precautions are necessary. If too much sludge is wasted at any one time, the sludge settling rate will usually increase rather than decrease. In such cases, the mixed liquor concentration is reduced immediately without inducing a comparable reduction in sludge age, and the thin sludge will settle faster than a thicker sludge of equal quality. Secondly, the sludge may become extremely slow settling and bulky if the wasting rate is increased too much for too long. This will usually occur when the newly developed slow settling young sludge forms too great a proportion of the total sludge mass.

Sludge wasting rates should no longer be increased, and most probably should be reduced slightly, when the SSC trend line starts falling at an accelerated rate.

The "ashing" and "clumping" in the final clarifier and dark scummy foam on the aeration tanks, associated with old sludge, are practically always eliminated when proper sludge quality is restored.

Slow Settling Sludge

Sludge Concentration Control

The settling rates of equal quality activated sludges (similar SSCs) vary according to changes in mixed liquor concentrations (ATCs). *Thin, low ATC sludges (of equal quality – SSC) settle faster than thicker, high ATC sludges.*

At times the activated sludge system can become glutted with excessive sludge solids at excessively high mixed liquor concentrations before the sludge age increases to the point where settling rates are normally increased. Excessive mixed liquor concentration can be reduced, settling rates can be increased and the clarifier sludge blankets lowered, in such cases, by increasing the sludge wasting rate sharply (maybe doubling or tripling the previously established rate) for short time periods until the clarifier sludge blanket retreats to safe levels.

Such "blast" wasting should be discontinued as soon as possible to avoid wasting all the way over to the sludge bulking stage.

Sludge Quality Control

The settling rates of equal concentration (ATCs) activated sludges vary according to changes in mixed liquor sludge quality (SSCs). *Young, low SSC, sludges (at equal ATC) settle slower than old, high SSC, sludges.*

On a *long-term* basis, and if the plant is not consistently overleaded, bulking can usually be eliminated by reducing the established wasting rate to increase sludge age.

But this maneuver becomes difficult at times. If wasting is reduced too sharply, or discontinued altogether, the newly developed (slow settling) young sludge proportion of the entire sludge mass may *start* to increase more rapidly than the old sludge portion. This would reduce, rather than increase, both sludge age and sludge settling rates initially.

Multiple dilution settlometer tests will indicate whether or not an initial short spurt of "blast" wasting is called for before the long-term reduced wasting program is initiated. Multiple dilution tests should be run simultaneously on three portions of the mixed liquor sample. One settlometer should contain 100 percent mixed liquor, the second one about 75 percent mixed liquor and 25 percent final effluent and the third one should contain about 50 percent mixed liquor and 50 percent final effluent.

An initial *temporary* spurt of "blast" wasting will be appropriate if the diluted sludges settle faster *and* concentrate to SSC values equal to or greater than the SSC of the undiluted sample. Blasting would be discontinued and sludge wasting should be reduced as soon as the sludge blanket recedes below the clarifier surface water level. Wasting can then be reduced (to increase SSC and improve sludge quality) when the sludge blanket remains safely at lower levels.

Clarifier sludge flow control adjustments must obviously be coordinated with the wasting adjustments. Changes in sludge quality induced by the wasting program will be revealed by the changes in the settled sludge concentration curves which in turn are used to calculate the current clarifier sludge flow percent demand.

"STEP-FEED" OPERATION
(Discussed in Part III-B)

Aeration tanks that are arranged for step-feed loading provide excellent operational flexibility and can be extremely effective in combating transient overloads or poor activated sludge quality. In a four bay step-feed aeration tank, for example, all return sludge is routed to the first bay but the wastewater can be treated in the plug-flow mode, the contact-stabilization mode or any place in between.

Such aeration tank arrangements provide a most effective means for curing slow settling sludge bulking by operational control adjustment. If the sludge settling rates are starting to slow down, most of the wastewater can be routed from the first bay to the second, or to the second and third bay to increase the *sludge oxidation* pressures. If serious bulking is occurring, most of the wastewater may be sent directly to the fourth bay in contact-stabilization fashion to induce maximum sludge oxidation. In these cases, mixed liquor concentrations leaving the fourth aerator bay are reduced because more sludge solids are maintained in the first, second or third bays. Return sludge flow rates can therefore also be reduced and the activated sludge will remain in the aeration tanks for more hours per pass and for more hours per 24-hour cycle.

If the one hour SSC values for bulking sludges are extremely low (say below 6 or 7), return sludge alone (no wastewater) should usually be routed to the head end bay, or bays. When sludge quality improves (SSC increasing to 8 or higher levels), however, some wastewater should again be routed to the first bay to avoid building aerator sludge concentrations up beyond the oxidative capacity of the aeration devices. It is usually desireable to start sending about 1/3 of the wastewater flow to bay one when SSC values start increasing significantly. The percentage of wastewater flow routed to bay one can then be further increased while SSC values continue rising towards optimum.

This same procedure can be used during rainstorm induced hydraulic overloads. If the storms do not last too long, a high percentage of the activated sludge will be stored in the first two or three bays, instead of being flushed out of the final clarifier, if most of the wastewater is routed toward the outlet end aeration tank bay or bays. Furthermore, when shifted to the "step" or "contact" mode the clarifier can handle increased surface overflow rates because the lower concentration mixed liquor (of equal quality) leaving the fourth bay of the aeration tank will settle more rapidly than the higher concentrated mixed liquor concentration that prevailed during plug-flow operations.

When good sludge quality is restored, the *wastewater treatment* pressures can be maximized by reverting back towards the plug-flow configuration to increase the *wastewater* detention time in the aeration tanks.